FOREWORD

For most of us, air travel isn't an adventure anymore. We take it for granted that we can climb aboard a well-built, reliable aircraft and fly wherever we want swiftly, safely and efficiently.

That confidence didn't come out of a clear blue sky. It is inspired by modern technology and innovative design—much of which comes directly from the pioneering aeronautics research by NASA and its predecessor, the National Advisory Committee for Aeronautics.

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WITH NASA'S HELP, THE UNITED STATES WILL CONTINUE ITS LEADERSHIP IN THE FIERCELY COMPETITIVE WORLD AEROSPACE MARKETPLACE

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But NASA isn't content to live on its reputation. Today, our aeronautics programs are remarkable for their scope and diversity.

They are also characterized by a strong partnership with American industry and universities.

The research itself is complicated, but the underlying goal is simple: to provide technology that can change the shape of tomorrow's aircraft literally from nose to tail.

Some changes derived from NASA research will amount to a subtle revolution. There will be new electronic systems, increased use of advanced materials and quieter, more fuel-efficient engines.

Other achievements will be more dramatic, leading to new classes of aerospace vehicles such as a next-generation supersonic transport and the X-30 National Aero-Space Plane.

With NASA's help, the United States will continue its leadership in the fiercely competitive world aerospace marketplace as we head toward the 21st Century. And that has profound implications for our economy, for our civil transportation and for our national defense. ➤

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Overleaf:
Full-scale aircraft testing in the 30 x 60-foot wind tunnel.

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INTRODUCTION

ORIGINAL CONTAINS COLOR ILLUSTRATIONS

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Enormous fans roar to life and air rushes over a full-scale airplane in the cavernous test section of a huge wind tunnel . . .

A sleek black SR-71 research aircraft hurtles over the California desert at more than three times the speed of sound to gather information on high-Mach flight . . .

Swirls of color fill a computer monitor as a lightning-fast supercomputer calculates airflow over a design for the National Aero-Space Plane . . .

* * *

These are just a few faces of National Aeronautics and Space Administration (NASA) aeronautics research: bold, forward-looking endeavors on the cutting edge of aerospace technology that have kept the United States at the forefront of aviation for more than 75 years.

It's difficult to overestimate how important aeronautics research is to the nation's economic health and competitiveness. American aerospace firms employ hundreds of thousands of people and the companies' exports are the major positive factor in our trade balance.

NASA uses its wealth of scientific and engineering resources to advance both civil and military aviation. Some of its efforts, such as research to prepare technology options for a next-generation supersonic transport, may take 10 years or more to come to fruition. Other NASA work is aimed squarely at more immediate problems—for instance, the aerodynamic performance of twin-tailed supersonic fighters at high angles-of-attack.

NASA researchers are part of a coast-to-coast team that includes government, industry and academia. NASA and the Federal Aviation Administration (FAA), for example, conduct joint research activities in several key safety and technology areas. The agency and the Department of Defense are partners in a wide range of cooperative programs in every speed regime from subsonic to hypersonic. And about half the test hours run in some of NASA's busiest wind tunnels are devoted to projects of the U.S. aerospace industry.

In addition to joint efforts, NASA ensures that the results of its research are available to the U.S. aerospace community through technical reports, conferences and workshops. The agency also has a vigorous set of university programs designed to broaden its base of technical expertise and to nurture the education of future aeronautical scientists and engineers.

These other government and private entities request NASA's participation because the agency has a unique mix of talented people and invaluable research facilities. The agency has four aeronautics-oriented installations that represent an unparalleled national asset: Langley Research Center in Hampton, Virginia; Lewis Research Center in Cleveland, Ohio; Ames Research Center in Moffett Field, California and its Dryden Flight Research Facility at Edwards Air Force Base in California.

Full-size F/A-18 fighter in Ames Research Center's 80x120-foot tunnel.

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NASA has structured its aeronautics research program into six broad areas or "thrusts." The intent is to combine planning activities into an integrated, strategic operating scheme and to provide program stability in the face of an uncertain budgetary climate. These thrusts represent the direction of NASA aeronautics research now and in the future:

➤ **Subsonic Aircraft**—Developing selected new technologies that will ensure the competitiveness of U.S. subsonic aircraft and enhance the safety and productivity of the nation's airspace.

The technology challenges in the subsonic thrust are varied. Much of NASA's research focuses on reducing drag and improving lift—advances that could lead to significantly better fuel economy in tomorrow's airliners. Coupled with that work are efforts to design quieter and more efficient engine concepts and to reduce aircraft weight through increased use of composite materials. NASA and the FAA are also working together to enhance safety in the nation's airspace by improving onboard cockpit technology and air traffic control systems.

➤ **High-Speed Transportation**—Resolving critical environmental issues and laying the technological foundation for an economical next-generation supersonic transport.

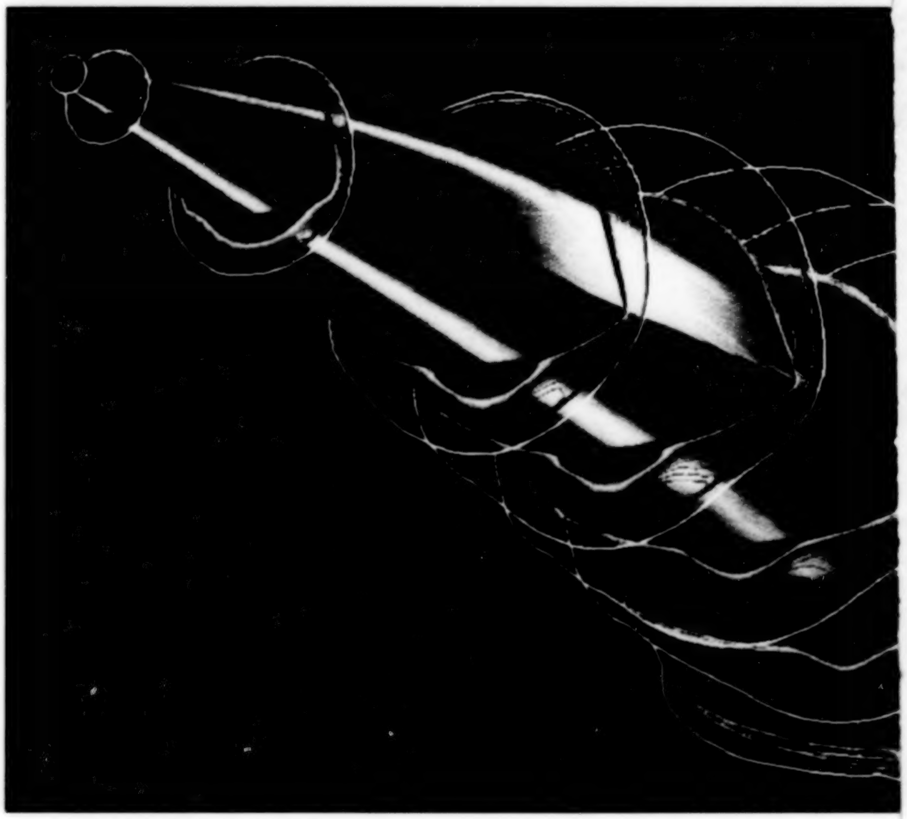
Many aviation experts forecast that a fleet of high-speed airliners will be flying the world's transoceanic air routes early in the 21st Century. They also predict that the American aerospace industry will remain competitive only if it is a major player in that aircraft market. NASA's High-Speed Research Program is aimed at the environmental and technological questions that must be answered before private industry commits its resources to build a supersonic transport aircraft.

➤ **High-Performance Military Aircraft**—Providing technology options for revolutionary new capabilities in future high-performance fixed- and rotary-wing aircraft.

NASA's research on high-performance aircraft is directed at challenges, such as controlled flight at high angles-of-attack, that will ensure U.S. pilots continue to fly the best planes in the world. It also develops technology that helps improve the performance of the current generation of military aircraft.

➤ **Hypersonic/Transatmospheric Vehicles**—Developing critical technologies for the X-30 National Aero-Space Plane and future hypersonic vehicles.

The X-30 will be a unique flight research vehicle. It will be able to take off horizontally like an airplane, fly into orbit using air-breathing engines for its primary propulsion, then



Computer-generated computational fluid dynamics (CFD) simulation showing Mach contours of National Aero-Space Plane.

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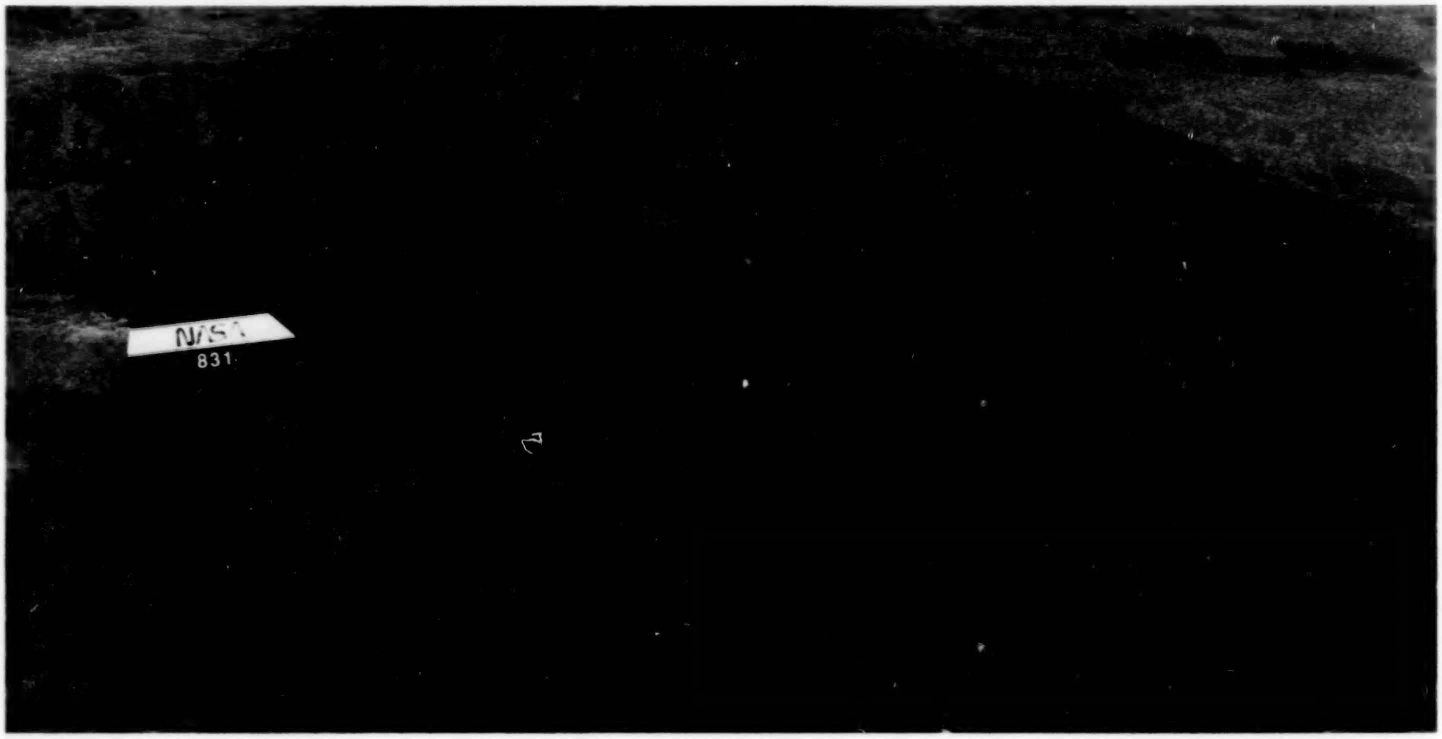
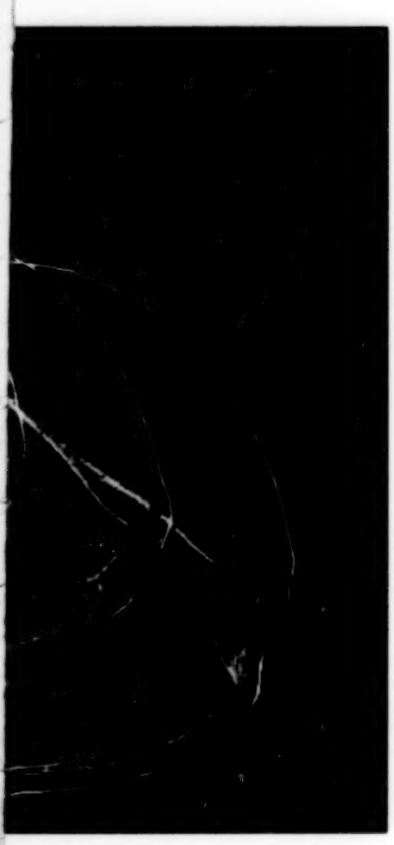


NASA SR-71B Mach 3+ research aircraft.



return through the atmosphere for a runway landing. NASA's activities are directed at the formidable technological hurdles in propulsion, aerodynamics, materials and system integration that are needed for this vital national endeavor to succeed.

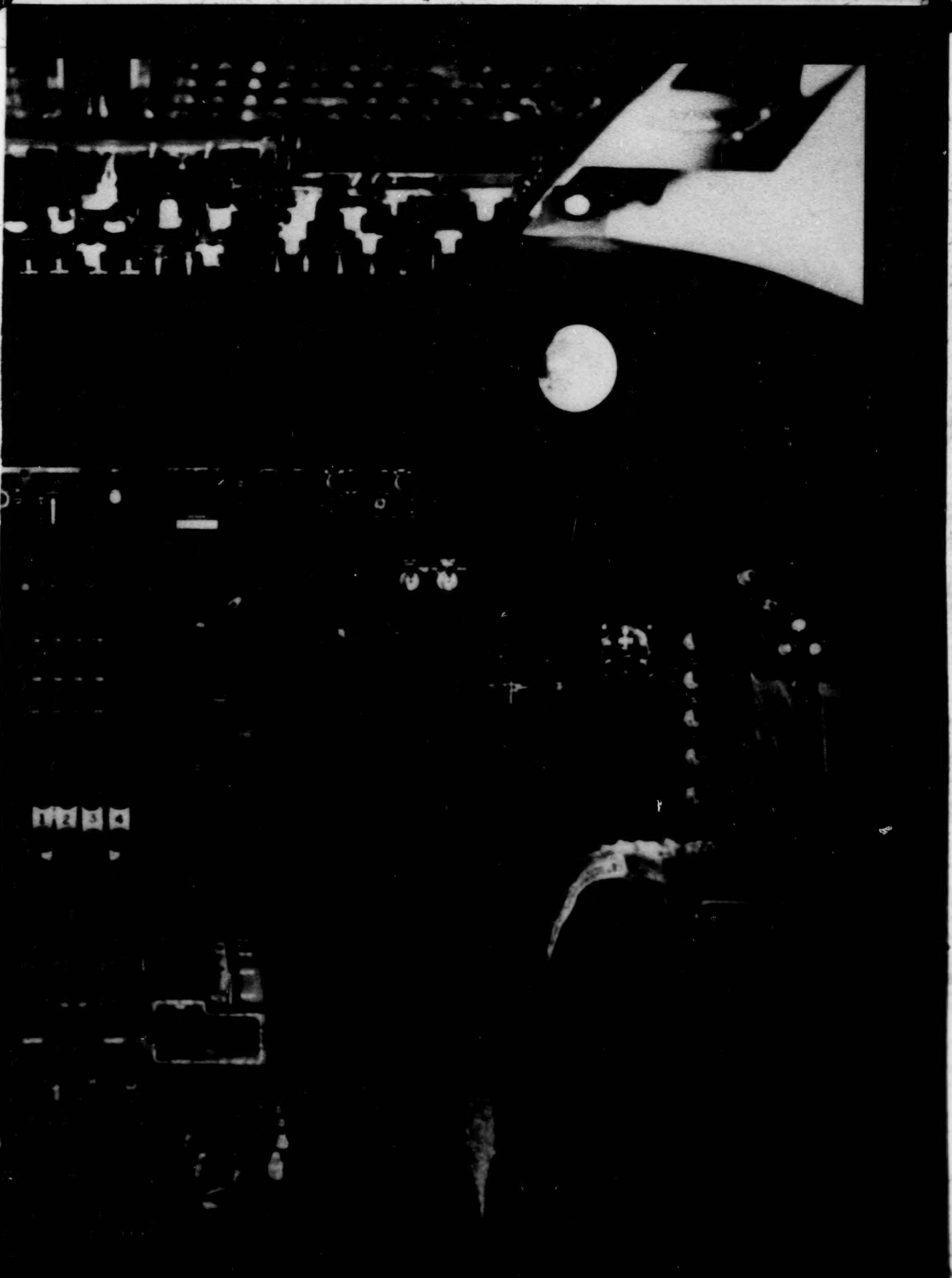
- ➤ **Critical Disciplines**—Pioneering the development of innovative concepts and providing physical understanding and theoretical, experimental and computational tools required for efficient design and operation of advanced aerospace vehicles.

  NASA strongly supports research in technical disciplines important to aviation. The emphasis is on fundamental knowledge of physical phenomena critical to the performance of aerospace systems. NASA's efforts also try to identify and develop new ideas that may produce revolutionary advances in a given discipline.

- ➤ **National Facilities**—Enhancing, maintaining and operating NASA's vital aeronautical research facilities.

  The agency operates some of the world's premier aerospace testing facilities. To strengthen the ability of these unique national assets to meet U.S. aeronautical research goals, NASA is upgrading many of its facilities through a comprehensive revitalization effort while continuing to bring new capabilities on-line.

With these thrusts as the core of its aeronautics program, NASA will continue to make valuable and timely contributions to advanced aircraft designs, improvement of air traffic operations and safety. ➤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SUBSONIC AIRCRAFT

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Developing selected new technologies to ensure the competitiveness of U.S. subsonic aircraft and enhance the safety and productivity of the nation's airspace.

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To the casual observer, the subsonic aircraft of the early 21st Century may not look significantly different from today's generation of airliners. But recent technological developments spurred by NASA research are merging to create a revolution in tomorrow's transport aircraft. Innovative wings, ultra-efficient propulsion systems and composite materials are setting the stage for a new era in commercial air travel.

NASA is working closely with aerospace manufacturers, airlines and the Federal Aviation Administration (FAA) to research and introduce advances that will keep the United States in its traditional position as leader of the commercial aviation marketplace.

WINGS TO COME

Flight is a careful balancing act between upward aerodynamic force—"lift"— generated by an aircraft's wings and air friction—"drag"—that slows a plane down. Much of NASA's research in the subsonic area is devoted to increasing the ratio between those two forces to make transports more fuel-efficient and safer during takeoff, cruise and landing.

NASA ran a series of wind tunnel tests at Langley Research Center in 1990 to study combinations of flaps and slats that could increase lift on advanced transports. The agency also performed high-lift experiments using Langley's Boeing 737 Transport Systems Research Aircraft. The plane's three-part flaps were deployed at settings of 15, 30 and 40 degrees, while cameras and sensors gathered data on airflow, surface pressures and skin friction. The test results are being used to refine computer simulations of the aerodynamic effects of high-lift devices and will ultimately lead to improved high-lift systems.

Improving high-lift systems on airliners will reduce takeoff noise "footprints" because planes can climb out more quickly. The higher lift-over-drag ratio will also allow designers to reduce wing area and weight, with a resulting increase in range and payload.

Drag is the other nemesis of aircraft efficiency, so NASA has a continuing program to characterize drag and to develop ways to combat it. In a joint effort among NASA, Boeing and the Air Force, a Boeing 757 airliner was equipped with a suction system on its left wing to siphon off turbulent air rushing over the surface. The resulting laminar (smooth) flow of air was followed by a run of laminar flow naturally produced by the plane's carefully shaped wing. This "hybrid" technique to reduce drag could produce significant fuel savings if a full-scale, operational system were mounted on the U.S. transport fleet.

As the turbofan engines mounted on commercial airliners become more powerful, the size of the engine nacelles relative to the wing will have grown dramatically. NASA performed an experimental program at Langley in 1989 to determine the aerodynamic penalty imposed by large, high-bypass-ratio "superfan" nacelles on advanced transport-type aircraft. The wind tunnel tests confirmed that the larger nacelles produce higher drag, but also showed that drag is offset by the increased fuel efficiency of the turbofans themselves.

NEW MATERIALS FOR NEW AIRCRAFT

What if future commercial aircraft components weighed about half what they do now and cost only three-fourths as much?

NASA is conducting an aggressive effort to understand and develop new composite materials that have the potential for large weight savings and much better resistance to corrosion. Breakthroughs in these materials may permit structures made from epoxy-type resins and high-strength carbon fiber to replace metals in the wings and fuselages of next-generation commercial transports.

In the first phase of the agency's Advanced Composites Technology program, 14 of the nation's most respected

Tomorrow's passenger aircraft will have even better fuel efficiency and more advanced systems than current state-of-the-art airliners like the Boeing 747-400.

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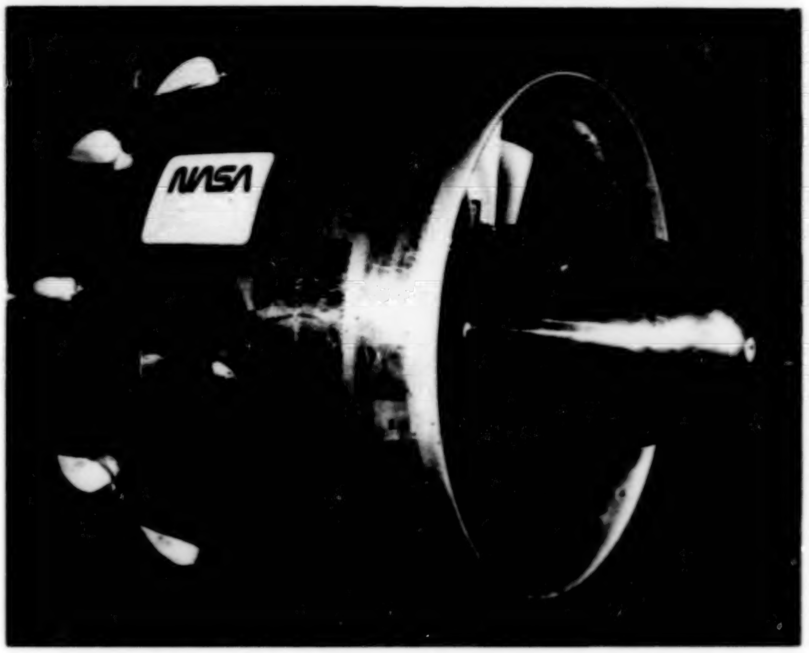
aerospace firms and universities have focused on fundamental composites research to come up with innovative, cost-effective ideas. "In-house" researchers at Langley and Lewis Research Centers are also involved.

Langley, for example, conducted several studies in 1990 on the reaction of composite structures to wear and tear. One investigation characterized the matrix cracking and delamination that composites experience before failing completely. Other efforts looked at the energy-absorbing capabilities of composite tubes and



Pratt & Whitney advanced ducted propeller tested at Lewis Research Center. Detailed laser velocimeter data documented external flow field for reverse and forward thrust to verify source noise reduction codes.

CENTER TRACON AUTOMATION SYSTEM (CTAS)

NASA IS WORKING TO HELP AIR CONTROLLERS HANDLE THE EVER-INCREASING VOLUME OF TRAFFIC IN THE NATION'S AIRSPACE. HEINZ ERZBERGER OF NASA'S AMES RESEARCH CENTER DISCUSSES THE DEVELOPMENT OF ONE POWERFUL NEW COMPUTERIZED TOOL: THE CENTER/TRACON AUTOMATION SYSTEM (CTAS).

Air traffic flow is an organic situation that progresses almost from takeoff to landing. We are concentrating on arrivals with CTAS because they go to the worst bottleneck, the runway.

CTAS has three highly integrated components. There is first what I think of as an "orchestra conductor": The Traffic Management Advisor. It looks at aircraft as they come in from all directions, 200 to 300 miles out, and it starts to develop a plan to handle that traffic effectively.

We then provide aids to help controllers implement that plan. One such aid, Descent Advisor, generates graphic representations of spatial and time relationships among aircraft converging on an aerial "gate." The Final Approach Spacing Tool, or FAST, lets controllers make precise corrections to aircraft positions after the planes have flown through the gate.

So with CTAS, controllers always have a plan and advisors to implement the plan. It's a dynamic plan, which changes as the traffic situation changes, and the advisors are there all the way to landing.

The original research for CTAS goes back to the late 1970s, when we really began to examine the air traffic process. In the early 1980s, we started to adapt trajectory analysis studies done for on-board flight management systems to the ground controller's point of view.

Simultaneously, graphics-oriented computers, as exemplified by the Macintosh, arrived. From that technology grew the idea that we could make various tools available to controllers that would let them bring up trajectory knowledge to make predictions in a convenient way.

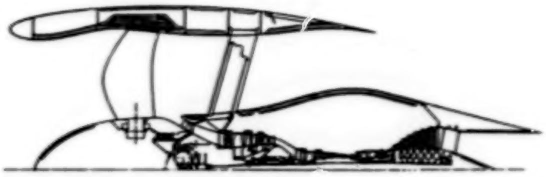
We have also been encouraged by the response of visiting teams of controllers who have worked traffic with CTAS tools on our simulator. They often tell us they want to take the system with them to use at their facilities.

We have made tremendous strides in explaining the CTAS concept to the air traffic community, including the highest levels of FAA management. Early in 1991, for example, we demonstrated the system to then-FAA Administrator Admiral Busey in our laboratories here at Ames.

But NASA and the FAA don't believe we can achieve our real objective simply by doing simulations in the laboratory. So as a consequence of the meeting with Admiral Busey, and numerous other conferences, FAA decided to pursue a test and evaluation effort in the field, with NASA responsible for major elements of the field systems.

FAA selected Denver and Dallas/Fort Worth areas for CTAS evaluation and testing. Both areas have "corner post" operations; that is, traffic is funneled through four gates as it enters the terminal area. Dallas/Fort Worth is especially complicated because of its many satellite airports and its substantially higher traffic level. In fact, it's a major challenge to see how we can adapt CTAS to that situation.

We are currently testing the system without disrupting the air traffic control process through what we call "shadow control." We drive the CTAS software with live radar data and notice how the advisories beams and attempted to find similarities in the response of metal and composite structures to crash loads. With this knowledge, engineers will be able to design better composite airframe structures and predict their service life more accurately.



Lewis Research Center sponsored studies of high-efficiency core engines. Typical in-line configuration shown here would have an advanced gearbox, high-efficiency compressor and would incorporate composite materials in its combustor and turbine.

TOWARD TOMORROW'S ENGINES

As subsonic turbine engines have evolved, engineers have put into their designs ever-higher bypass ratios to increase propulsive efficiency. One way to get even better performance may be to advance technology in engine compressors, combustors and turbines.

NASA's Lewis Research Center sponsored studies by engine manufacturers Pratt & Whitney, General Electric and Allison on the potential benefits of advanced core technology. The studies predicted that advanced cores could reduce fuel consumption 20-30 percent and might lower operating costs by 6-14 percent (assuming fuel costs of $1.00/gallon). The engine makers also found that the advanced technology would provide better thermal efficiency accounting for 60 percent of the expected improvement in performance.

The Center/TRACON Automation System will be tested in "shadow mode" at Dallas/Fort Worth Airport.

react to the traffic. In this first stage, however, we don't actually use the advisories, so our ability to evaluate CTAS performance is limited. But it has helped us to tune up the software.

This is still a research and development effort; NASA isn't building a production system. But the CTAS concept could migrate into the Advanced Automation System, a new air traffic control system that the FAA is working on for the late 1990s. Eventually, controllers may be able to handle more traffic with the same workload or the same level of traffic with less workload. In any event, the stress of air traffic control would be greatly reduced, and fuel consumption and delays would be minimized. ►

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HYBRID LAMINAR FLOW CONTROL

Efforts to produce laminar (smooth) airflow over aircraft wings have been around since the 1940s. The reason is simple: Smoother airflow translates into better aircraft performance and fuel economy. But the real challenge has been to make laminar flow control methods practical. Dal V. Maddalon at Langley Research Center explains NASA's work on one very promising technique—hybrid laminar flow control. ►

One way to control the boundary layer and obtain laminar flow is shaping the wing to obtain a favorable pressure distribution that maintains the smooth airflow. That's referred to as natural laminar flow. The problem with natural laminar flow is that it can be applied only to small aircraft or aircraft that have very little wing sweep. Commercial transports cruising at high speed need to have swept wings, and that introduces more complexity into boundary layer control.

It's possible to suck some of the boundary layer airflow through the surface of the wing, which removes the very unstable air next to the wing surface. That makes the flow more stable and maintains laminar flow further downstream, even in the presence of wing sweep. But until recently, the introduction of the suction surface and ducts into the wing structure was judged to be hopelessly complex.

A key development has been the evolution of a practical suction surface. An electron beam or laser is used to drill a myriad of microscopic holes in thin titanium sheets. That gives us a very practical surface that doesn't require a lot of maintenance and is quite durable.

Another key development has been the hybrid concept we recently (in 1991) flight-tested on a Boeing 757. This is a marriage of natural and active suction techniques for controlling the boundary layer—hence the term "hybrid." It greatly reduces the extent of the suction area and avoids sucking in the wing box structures. The idea is to use suction on the leading edge of the wing (just to the front spar of the wing box) where the sweep effects predominate. Further back on the wing the suction is absent, and we rely on the natural approach to get an extended amount of laminar flow.

We modified the left wing of the 757 by removing the leading edge for a span of about 20 feet outward of the left engine pylon. Then we installed a new section that had all the systems required to perform air suction. The contour of the leading edge was also changed so that we modified the pressure distribution over the entire chord of the wing.

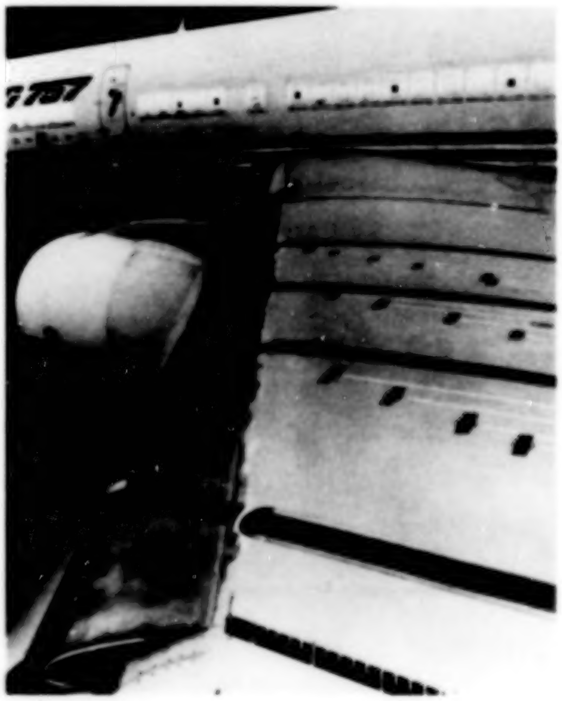
We also modified the new leading edge with a Krueger flap, which is a high lift device that is different from the slats on most aircraft. It deploys from the lower wing surface and increases the camber in the chord of the wing's lifting surface on takeoff and landing. In the hybrid concept, it also protects the leading edge of the wing against insect impacts that can clog the control surface or create roughness to trip the flow and cause turbulence.

The flight test results were very encouraging. We expected laminar flow possibly as far downstream as 40-45 percent chord on the wing. We actually got it to run all the way back to the shock wave, which is at 65 percent chord. The experiments also demonstrated that the suction required amounts to only one-third of that indicated by earlier design calculations.

The hybrid laminar flow control program with NASA, Boeing and the Air Force was industry's first flight research on this concept—and I think the flight experiments really opened their eyes. There's now intense interest in hybrid laminar flow. To get the full benefit of the hybrid technology, industry would design an airplane with a clean sheet of paper; the airplane would actually be resized to reflect the benefits of the drag reduction. They should realize fuel savings in the neighborhood of 15-20 percent on a commercial transport.

The hybrid effort involved a lot of organizations. NASA took the initiative in the 1970s to revisit laminar flow. But we couldn't have made the progress we have without industry. Yet I think industry wouldn't have pursued the technology development without us. The Air Force also played a very key role in their support of the program with the 757.

I think this program is an excellent indication of the accomplishments we can have when NASA works closely with the rest of the aeronautics community. ►



Langley Research Center participated in tests during 1990 and 1991 of a partial-span Hybrid Laminar Flow Control (HLFC) system on a Boeing 757. The 22-foot section contained laser-drilled holes and was protected by a Krueger flap. Wing surface instrumentation such as pressure orifices, pressure belts and temperature-sensing hot-films are shown covered by protective tape.

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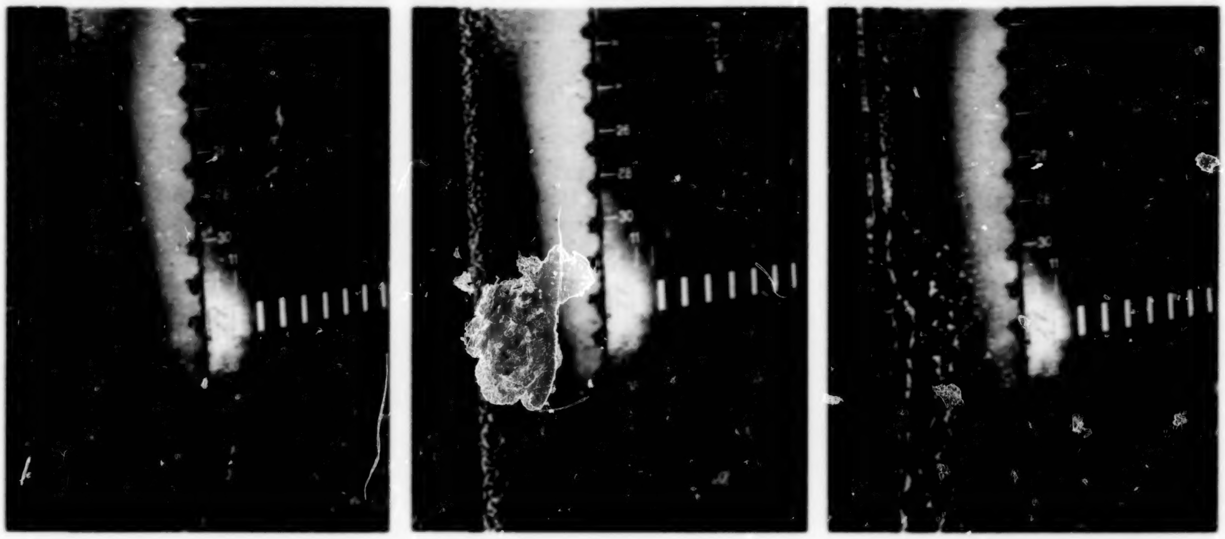


NACA 0012 airfoil with 21-in. chord in Lewis' Icing Research Tunnel for low-power deicing tests. Six companies furnished eight different pneumatic and electromechanical systems that cracked, debonded and expelled ice built up in IRT runs.

Lewis also has a continuing program that looks at the flow physics of multi-stage compressors for tomorrow's subsonic engines. The research is aimed at an improved understanding of the complex mixing phenomena that regulate the compressors' performance.

Reducing jet engine noise is one of the major areas of the joint NASA/FAA research agreements signed in 1990. The effort focuses on noise reduction technology, better understanding of noise effects and development of noise reduction standards for new aircraft.

One promising way to lower subsonic engine noise is to use ultra-high-bypass engines with advanced ducted propellers. But a ducted propeller poses its own design challenges. For instance, neither the unsteadiness of the airflow through the fan blades as the angle-of-attack changes nor the resulting noise had been studied extensively, because practical ducted propellers are a relatively new concept.

In 1991, NASA researchers completed development of a new computer code that permits precise three-dimensional analysis of unsteady airflow inside and outside ducted propfans. The code, which is an extension of work that the agency did on unducted propellers, has demonstrated accurate predictions of pressure losses at the fan face at angles-of-attack up to 40 degrees.

NASA also experimentally evaluated a Pratt & Whitney engine with a short duct (for low drag and weight) and thrust-reversing capability at Lewis Research Center. The tests collected acoustic data on the powerplant and assessed its aerodynamic performance.

The tunnel runs showed that the short inlet was very efficient and yielded low propeller blade stresses at the angles-of-attack typical of climbout from an airport. The noise measurements, made directly at the blade face, will help engineers understand the mechanisms that generate noise in ducted systems—knowledge that could eventually produce even quieter ultra-high-bypass engine configurations.

TOWARD SAFER SKIES

With industry and other government agencies—especially the FAA—NASA plays a key role in making modern air travel safer for millions of passengers and pilots. The agency's research has three broad areas: weather phenomena and their effect on aircraft, new aeronautics technology and human factors.

In 1990, NASA wrapped up a program to model the effect of heavy rainfall on the lift generated by an airplane's wings. At Langley Research Center, a full-scale airfoil section mounted on a test carriage was sent hurtling through a simulated rain field at typical takeoff and landing speeds. The studies confirmed wind tunnel predictions that heavy rain causes a substantial loss of lift, making heavy rain an important factor that pilots and designers should consider in planning for bad weather operations.

DANGER—WIND SHEAR!

A close encounter with wind shear—a sudden change in wind speed or direction—can cause problems for even the best-built airplanes and most experienced pilots. Especially in the fickle weather of spring or summer, wind shears occur in capricious storms called "microbursts" that hide beneath harmless-looking cloud decks or lurk inside gentle shafts of rain.

As an aircraft enters a microburst, headwinds first cause an airspeed increase. The pilots' natural reaction, without proper training, is to reduce thrust to compensate. But as the plane penetrates the microburst's core, the headwind changes to a very strong tailwind, causing airspeed to drop. During takeoff and landing, an aircraft is usually very close to its minimum operating speeds, so any further reduction can cause a stall or an unavoidable loss of altitude.

In 1986, NASA and the Federal Aviation Administration (FAA) agreed to investigate the threat posed by hazardous wind shear. NASA's role was to develop advanced airborne sensors that can see ahead of an aircraft and detect a microburst before the plane enters it.

From 1987 until recently, researchers conducted an exhaustive set of analyses, simulations and tests and continuously coordinated the results with industry.

The studies found that with even a slight warning of wind shear conditions—as little as ten seconds—pilots are much more likely to take appropriate and timely action.

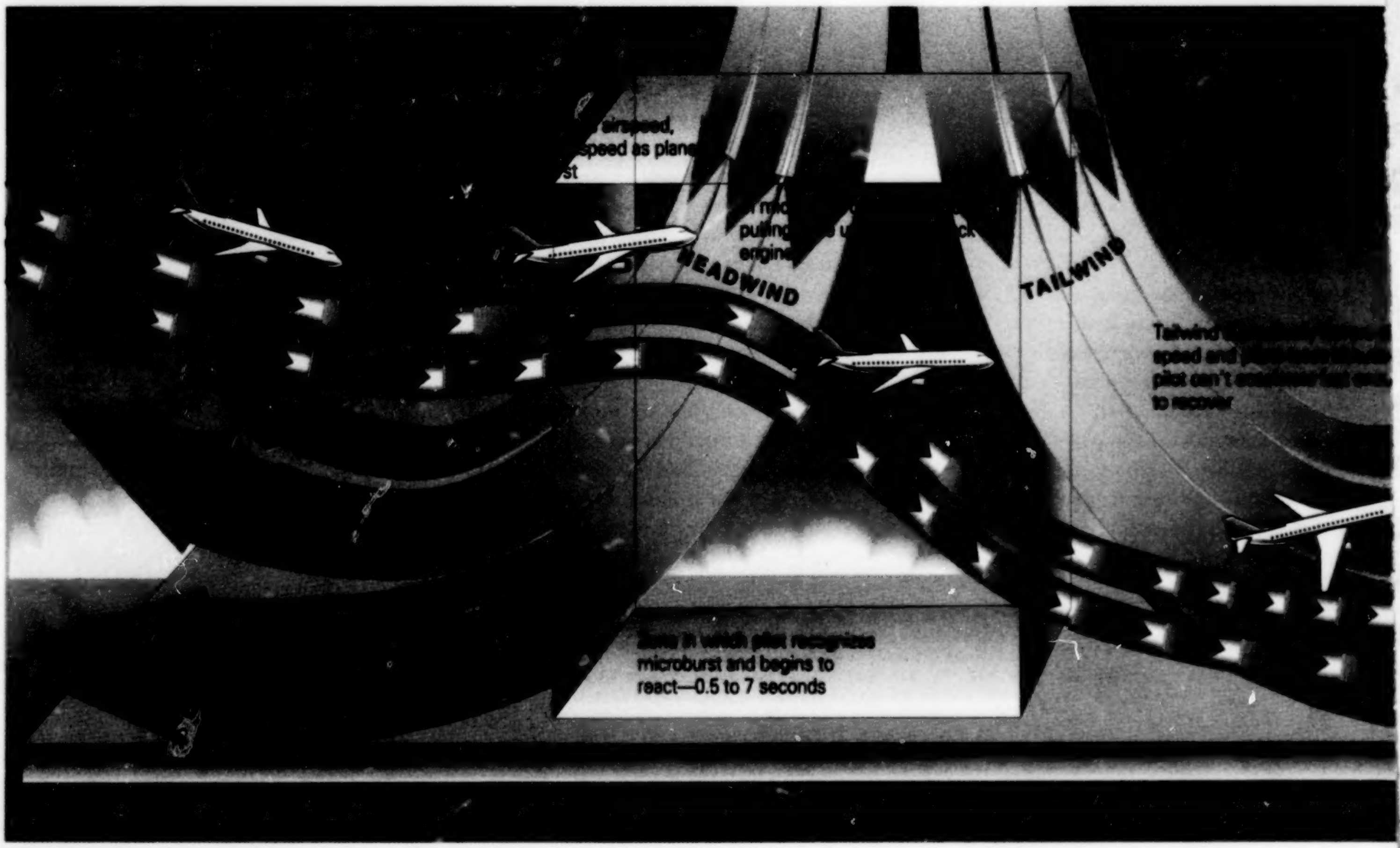
The results also showed that microwave radar, pulsed Doppler laser detection and ranging (lidar), and passive infrared are all potential candidates as forward-looking wind shear sensors.

Microwave radar locates a microburst by detecting the water droplets inside it. Lidar systems ferret out "dry" microbursts by picking up suspended particulate matter, but are blocked by excessive moisture. Infrared sensors detect the temperature difference between the generally cool core of the microburst and the surrounding air, but can be fooled by temperature variances that have nothing to do with microbursts.

NASA's Boeing 737 Transport Systems Research Vehicle made an important and dramatic series of wind shear-related flights in summer 1991. The plane was dispatched to Orlando (Fla.) International Airport and Stapleton International Airport near Denver. Its assignment: evaluate airborne wind shear sensors and their ability to send data to ground stations in these two areas where microbursts are common at that time of year.

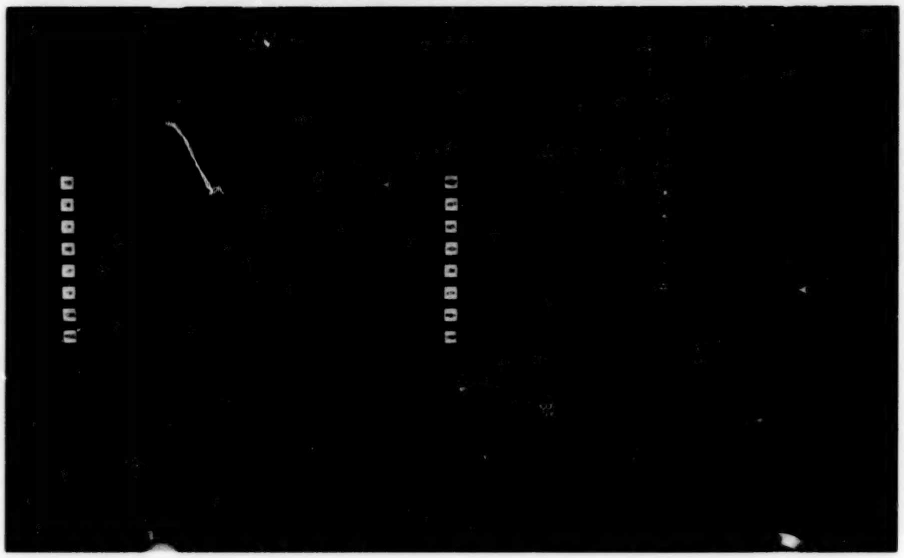
The Orlando experiments ran from June 9-21; the tests in Denver from July 7-25. Equipped with microwave radar and passive infrared devices, the 737 was ready to fly every day, and the mission was based on the forecast weather.

In clear weather, the plane gathered radar "clutter" data on airport approach paths and surrounding areas. When the forecast suggested conditions were right for microburst



formation, the 737 loitered above the ground-based Doppler radar station at a high, safe altitude. When the ground station found a wind shear event and safety criteria were met, the plane flew toward the storm and penetrated it as the sensors gathered data.

The tests are part of the process where each sensor's performance is checked against live conditions with all "real-world" variables present. NASA's research directly supports the FAA, industry and the airlines in their response to the wind shear threat. ➤



Bulls-eye displays used in NASA/Honeywell GPS autolanding tests. Left-hand display shows aircraft's present location and altitude. Right-hand display is centered on runway approach path and gives climb/descent rates.

NASA also has a comprehensive research program on the occurrence and effects of aircraft icing, with many experiments performed in Lewis Research Center's Icing Research Tunnel (IRT). A 1990 joint test program on low-power deicing systems involved investigators and engineers from NASA, the Air Force and industry. The tests measured how effectively the devices removed ice, the size and mass of the resulting ice particles and deicing power requirements.

REVOLUTION IN THE COCKPIT

During the past decade, automation has become an important factor in moving an awesome amount of air traffic relatively smoothly through American airspace. NASA is contributing to increased air safety by developing specific new piloting and air traffic control aids and finding out how people respond to those innovative systems.

At Langley Research Center, pilots evaluated a new information concept dubbed E-MACS (Engine-Monitoring And Control System). E-MACS sums up engine performance in a display that presents data as column indicators showing variances between real and ideal values. The pilots who assessed E-MACS preferred its format to the round dials and gauges found in many aircraft cockpits. Even more important, the test subjects detected every system's fault thrown at them during the simulations, compared to a 56-percent rate for more traditional displays.

Late in 1990, NASA also participated in a joint flight research project with Honeywell that may upgrade automated landing capabilities in future aircraft. Langley's Boeing 737 made 36 automated landings using a Honeywell differential navigation system linked to the Global Positioning System (GPS). GPS is a worldwide constellation of U.S. satellites that provides precision navigation information.

In commercial aviation, an automated landing system based on differential GPS inputs offers the potential for complete guidance in poor visibility conditions: precision approach from a variety of air traffic patterns, landing rollout and taxi to the gate.

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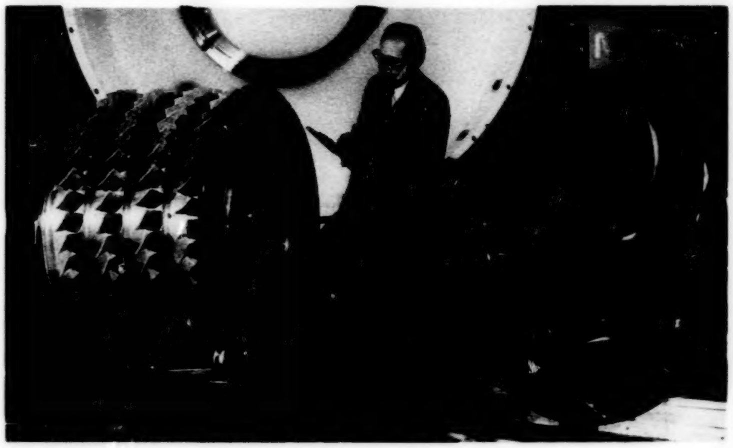
COLOR PHOTOGRAPH

In the future, expert systems—sometimes called "artificial intelligence"—may be used on commercial airliners. NASA researchers at Langley have designed a prototype system called Faultfinder that has proved its ability to diagnose failures in the engine and hydraulic subsystems of a "generic" aircraft using artificial intelligence techniques. Faultfinder was evaluated using eight actual accident cases selected from National Transportation Safety Board (NTSB) reports. The system used a computer simulation of each accident to produce a hypothesis for the probable cause of the failure, correctly "solving" seven of the eight test cases.

There have been a few incidents where the hydraulic controls on large aircraft failed during flight, leaving the pilots with almost no capability to land normally. In 1991, NASA investigators at Ames-Dryden Flight Research Facility did an engineering study that shows multi-engine aircraft with specially programmed flight control systems can touch down safely using just the plane's engines.

The work was done on a simulator that looked at the engines-only handling qualities of a variety of aircraft including large transports and a twin-engine jet fighter. NASA pilots also made preliminary flight evaluations in Ames-Dryden's F-15 research aircraft and two business-size planes. The flight tests confirmed simulator predictions that some control is possible using just the throttles, but landing tasks are extremely difficult unless the flight control system has been tailored for engines-only operations.



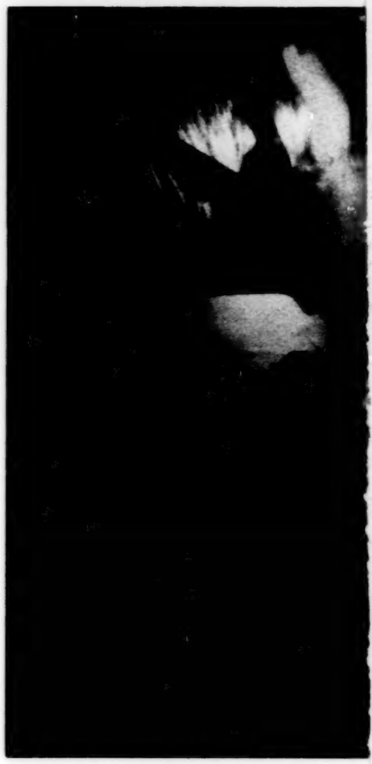
Lewis Research Center is replacing a large centrifugal compressor (right) with a four-stage axial-flow compressor (left) for low-speed mixing research. Researchers will be able to change blade stagger, solidity and relative circumferential positioning between the blade rows on the axial-flow apparatus.

THE "HUMAN ELEMENT"

Even with all the sophisticated technologies finding their way into aircraft cockpits, human beings still make the critical flight decisions. NASA's human factors research seeks out information about human capabilities and limitations, then applies those discoveries to the design and analysis of systems, tools, tasks and procedures. The goal: safe, effective and reliable flight.

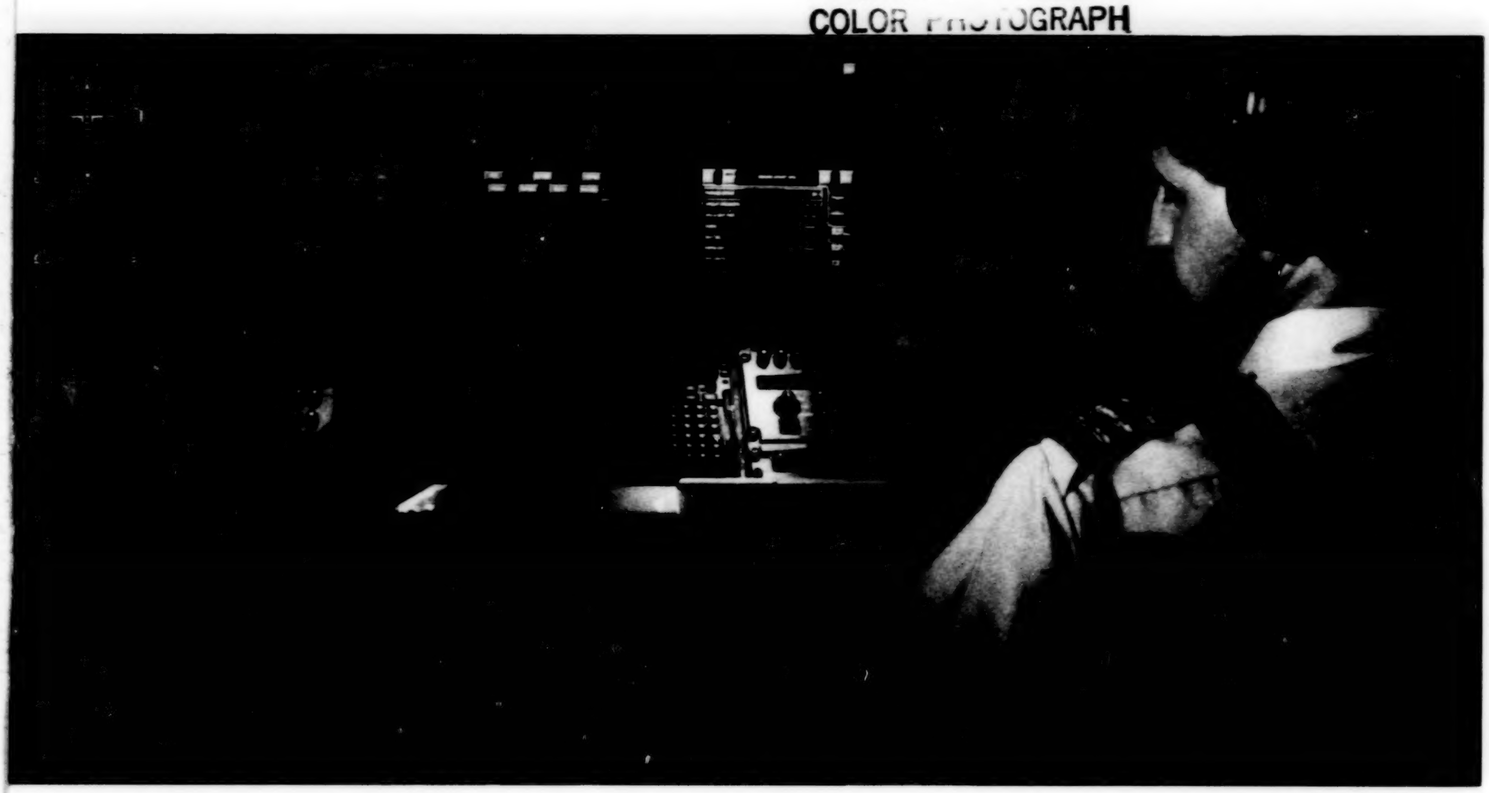
A primary purpose of NASA's work is to improve safety by supporting the development and integration of advanced automation concepts for aircrews and air traffic controllers. One of the first steps was to define how aircrews interact with automated cockpit systems under actual flight conditions.

From 1986 to 1989, NASA researchers at Ames Research Center coordinated a study of automation's impact on aircrews flying the highly computerized Boeing 757 twin-jet. They found many pilots were concerned about safety because of the amount of data presented and the tasks inherent in using state-of-the-art flight management systems. Almost half the participants worried that automation would diminish their piloting skills, yet nearly all of them said they were comfortable flying with the 757's electronic flight deck.



NASA is also conducting the first major attempt to understand how and why crew performance suffers from fatigue and the impact of changes in the body's internal time clock. These field studies use cockpit observers and physiological monitoring devices to investigate pilot behavior. Volunteer crew members wear portable biomedical recorders that collect data on body temperature, heart rates and activity. In a cooperative program, research organizations and airlines in Germany, the United Kingdom and Japan collected electroencephalograph (EEG) sleep data during crew layovers on worldwide routes.

In 1990, the effort expanded to include a test of fatigue countermeasures during four successive transpacific flights by two groups of Boeing 747 crews. One group took a 40-



NASA researchers are studying how humans interact with highly computerized cockpits like that of the Boeing 747-400.

minute nap in their seats on a rotating basis; the other operated under their usual flight rules without sleep periods. According to EEG data and the results of portable laboratory awareness tests administered at intervals throughout the flights, the crews that took a preplanned rest were significantly more alert during critical flight phases than those who did not.

The results of these studies are shaping guidelines for flight regulations and aircraft certification and are aiding human factors researchers in their search for improved coping strategies.

THE AGING AIRCRAFT CHALLENGE

Economics dictates that airlines keep aircraft in service as long as they are safe to fly. Commercial carriers must perform frequent, time-consuming inspections to identify structural problems that could affect a plane's airworthiness—an endeavor that costs the airlines both time and money.

In 1991, NASA and the FAA expanded on their traditional cooperative efforts to address critical aging aircraft issues. In a wide-ranging agreement that draws on the respective strengths of each agency, the FAA will focus on fatigue and fracture analysis, corrosion, flight loads, human factors and nondestructive inspections. NASA's work will concentrate on improving methods of structural analysis and developing new inspection and evaluation techniques. For example, NASA's experiments at Langley Research Center have demonstrated that thermography (mapping of temperature differences) can detect disbonding in the lap joints of a typical aircraft structure. Quartz lamps heated test specimens, and an infrared camera measured the resulting temperature profiles. Comparison of the profiles before and after heating gives a clear image of any disbonding that has occurred.

An ultrasonic phased array technique developed at Langley shows promise for inspections in the field. Computerized signal processing provides high-resolution detection of potential problems and corrects inherent image aberration. Ultrasonic devices would be especially valuable in airline operations because they are able to find fatigue cracks and corrosion by scanning a large field of view during inspections.

The independent but coordinated research programs under way at NASA and the FAA form a technological foundation for the continued safe operation of the nation's commercial air fleet in a manner that responds to the concerns and needs of the air transport industry. ➤

HIGH-SPEED TRANSPORT

RESOLVING CRITICAL ENVIRONMENTAL ISSUES AND LAYING THE TECHNOLOGICAL FOUNDATION FOR AN ECONOMICAL NEXT-GENERATION SUPERSONIC TRANSPORT.

Shortly after the turn of the century, a fleet of American-made supersonic airliners may be carrying thousands of passengers per year at more than twice the speed of sound to points around the globe. To turn that dream into reality, NASA and industry are actively working on the technology needed to make possible a next-generation high-speed civil transport that will be profitable, reliable and environmentally compatible.

The emergence of several Pacific Rim countries as world financial powers makes the idea of a next-generation supersonic transport attractive. One obvious advantage is sheer speed: A trip from Los Angeles to Tokyo, for example, would take a little more than 4 hours instead of the 10 hours required by subsonic airliners.

The high-speed arena represents a future marketplace in which American industry must be competitive. U.S. companies have traditionally dominated world commercial airline sales, and the nation's aerospace industry as a whole produces an impressively favorable trade balance.

But there are major hurdles to overcome before routine supersonic travel becomes possible. Environmental questions about high-speed transports have increased as scientists have learned more about Earth's atmosphere. Also, the technology to build and operate such aircraft economically and within today's stringent airport noise standards doesn't yet exist.

Predicted pressure field around a McDonnell Douglas representative high-speed civil transport configuration.

Navier-Stokes computations were used to compute viscous flow over a high-speed civil transport configuration.

Overleaf: Numerical simulation model of high-speed civil transport.

INITIAL STUDIES

As a first step, NASA commissioned studies by the country's two largest transport aircraft manufacturers, Boeing and McDonnell Douglas. Their assignment: Define the potential market for a next-generation supersonic airliner and consider the engineering advances that would make it financially successful and environmentally safe.

Each company focused on a particular class of aircraft: McDonnell Douglas studied a Mach 3.2 design that could carry approximately 300 passengers a distance of 7500 miles. Boeing's Mach 2.4 concept could transport 250 passengers up to 5800 miles.

The firms reported their findings in late 1989. Their studies predicted that transpacific air travel will increase fourfold by the year 2000 and transatlantic passenger trips will double. Boeing concluded that a Mach 2.4 transport would capture more than 50 percent of the long-haul international market—as many as 1500 aircraft!

But both companies found that substantial demand for an advanced supersonic transport will occur only if the plane has no harmful atmospheric effects and meets allowable airport noise standards. It also must be economically competitive with future long-haul subsonic airliners. The aircraft's financial outlook would be enhanced by acceptable overland supersonic flight.

HIGH-SPEED RESEARCH PROGRAM

In 1990, NASA began an ambitious effort called the High-Speed Research Program as a logical follow-on to Boeing and McDonnell Douglas studies. It addresses the environmental concerns that could preclude full-scale industry development of a supersonic transport: emissions effects on the atmosphere, airport noise and sonic boom.

Jet aircraft exhaust expels oxides of nitrogen (NO_x) into the atmosphere, where they chemically react with and remove ozone. Advanced engines that will reduce NO_x emissions are the best solution, but researchers must also be sure they fully understand ozone depletion mechanisms.

In 1988, NASA created an advisory panel of international atmospheric science experts to guide the review and testing of current atmospheric models. One early finding was that current computer models

(continued on page 26)

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HIGH-SPEED TRANSPORTS: NO NOISY NEIGHBORS

Anyone who has watched the Concorde lift majestically from an airport runway has experienced firsthand the downside to the visual thrill: jet noise—often more than 120 decibels.

The reason the Concorde can be so loud is that existing community noise standards apply only to subsonic aircraft. But a next-generation high-speed civil transport (HSCT) will have to meet noise regulations for new subsonic transports on takeoff, approach and landing.

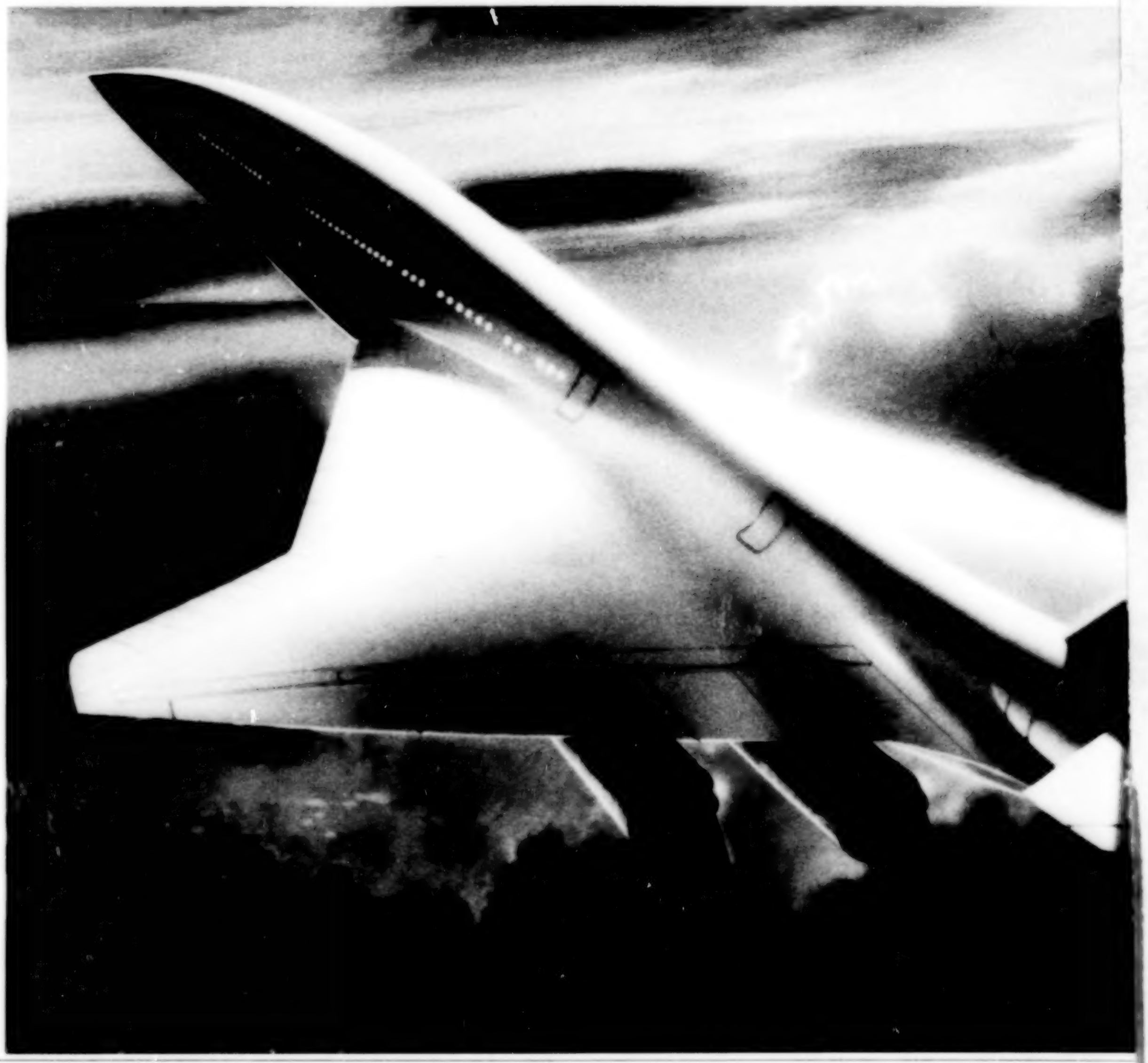
There are two ways to lower HSCT noise levels. The first is an engine configuration that has lower jet velocity at takeoff, much like today's high-bypass turbofans. But whatever engine ultimately powers an American supersonic airliner also must have good supersonic cruise performance. That mandates a high-velocity, turbojet-like cycle . . .exactly the opposite of characteristics that reduce noise.

NASA and two of the nation's leading powerplant manufacturers, Pratt & Whitney and General Electric, are evaluating technology choices for an engine cycle that will satisfy noise, performance and economic demands. Factors such as aircraft gross takeoff weight, emissions and noise levels are being used to compare and evaluate candidates. NASA and industry plan to have enough data by the end of 1992 to choose a concept on which the remainder of high-speed propulsion technology research will focus.

The second approach to the noise challenge is exhaust nozzle technology that will reduce sound levels while maintaining aerodynamic performance. "Mixer-ejector" concepts—nozzles that rapidly mix low-energy air from outside with the high-energy engine exhaust—appear to be the most promising design.

Current research centers on testing subscale nozzle concepts in NASA and industry facilities. NASA's Lewis Research Center evaluated a two-dimensional model of a Pratt & Whitney mixed-ejector design from June to September 1989. Researchers used the tunnel results to build a data base matching acoustic signatures to variations in model geometry. They also took pressure and temperature measurements at the nozzle's exit plane.

The success of the tests gave Pratt & Whitney enough data to design a full axisymmetric (symmetrical around an axis) nozzle concept that was evaluated during 1990. Engineers are using the information to make changes in the noz-



Boeing HSCT concept has long nacelles needed to incorporate advanced noise reduction technology.

MCDONNELL DOUGLAS

Mach 3.2 McDonnell Douglas supersonic airliner concept.

zle shape that will improve aeroacoustic performance.

Langley Research Center also is playing a major role in High-Speed Research Program noise studies. Engineers are testing a series of model generic nozzle configurations in the Jet Noise Laboratory. The results will yield a better understanding of each configuration's physical properties—knowledge that will help the nozzle studies at Lewis and those in industry.

The subscale investigations are also leading to refined computer codes that will be crucial for modeling low-noise nozzle performance later in the program. For example, the PARC Reynolds averaged Navier-Stokes code predicted localized hot streaks in the flow field of the Pratt & Whitney axisymmetric nozzle design. Infrared camera images shot during the runs in the Boeing facility correlated their existence. Langley Research Center and industry are also doing comparable assessments of other codes.

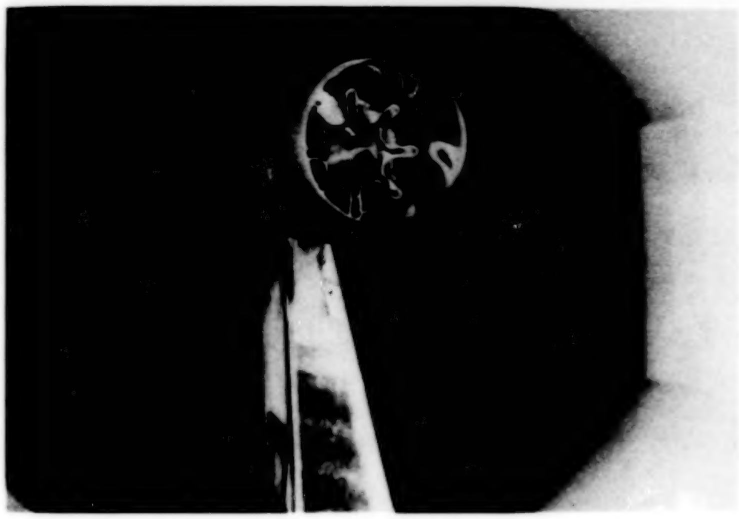
Experimental data and computer simulations on the subscale and generic nozzle concepts will help engineers select the most promising designs for tests in the huge 40x80-foot wind tunnel at NASA's Ames Research Center and in a jet exit rig at Lewis. The ultimate result: technology that industry can use to build the quieter supersonic transports of tomorrow. ➤

Two-dimensional Pratt & Whitney mixer-ejector nozzle in Lewis' 9x15 Low-Speed Anechoic Wind Tunnel. The tests surveyed the aerodynamic flow field and gathered near-field acoustic signatures for several different configurations.

don't adequately simulate the chemical reactions of NO_x with atmospheric particles such as the Earth's natural sulfate layer and polar stratospheric clouds. Scientists believe such particles contribute to ozone depletion at the poles during winter.

From 1989 to 1991, researchers tested the most reliable atmospheric computer models against existing atmospheric data to calculate the effects of emissions by a high-speed transport fleet. Although the results varied, the calculations showed that there were potential operating areas in the lower stratosphere where reduced engine emissions would deplete ozone by less than one percent.

NASA has several ER-2 aircraft (a civilian version of the famous U-2 reconnaissance plane) and a modified DC-8 jetliner that serve as the primary means to gather improved stratospheric measurements. In late 1991, an ER-2 and the DC-8 acquired the first ozone data geared specifically to the High-Speed Research Program as an adjunct to the Airborne Arctic Stratospheric Expedition II, a polar ozone mapping project.



Axisymmetric mixer-ejector nozzle in Boeing's Low-Speed Acoustic Facility. Tests are aimed at ultimately reducing jet noise by as much as 20 dB.

The ER-2s and DC-8 have limitations, however. The DC-8's altitude ceiling is lower than the height at which future high-speed transports would likely fly. For safety reasons, the ER-2 does not fly into the polar night that prevails in winter to take ozone measurements, nor does it travel more than about 200 miles from a coastline.

One candidate to increase high-altitude atmospheric sampling capabilities is a pilotless science research aircraft called Perseus, which could carry a 110-pound payload of instruments higher than 82,000 feet beginning in 1994. The prototype, built by Aurora Flight Sciences Corporation, has been successfully flight-tested.

Satellites also play an important role in gathering information on ozone depletion. NASA is getting high-quality measurements from spacecraft, such as the Upper Atmosphere Research Satellite (UARS) and Nimbus 7, and from a U.S. Total Ozone Mapping Spectrometer aboard a Soviet Meteor-3 satellite.

As data on atmospheric ozone come in, researchers continue to evolve and test models of high-speed transport emissions effects. The models will soon incorporate "heterogeneous" chemical effects, i.e., the interaction of exhaust products with atmospheric aerosols or particulates. Three-dimensional models currently being developed will let researchers include longitude in their simulations, which in turn should give a more realistic picture of the impact a high-speed transport fleet will have on the Earth's ozone layer.

Significant challenges in data gathering and computer modeling of atmospheric processes lie ahead. But NASA believes the atmospheric studies part of the High-Speed Research Program is socially responsible work that is essential to American industry's decision on pursuing a supersonic transport.

ULTRA-LOW NO$_X$ EMISSIONS

At 50,000-70,000 feet—the typical operating altitudes of future supersonic transports—one molecule of oxides of nitrogen (NO$_X$) in the aircraft exhaust could destroy many molecules of ozone. Lewis Research Center's Richard Niedzwiecki discusses NASA's efforts to study technology for jet engines that would emit very low levels of NO$_x$ while operating at highly efficient engine cycles.

➤

The focus of our research over the last two years has been to evolve the technology required to greatly reduce oxides of nitrogen (NO$_x$) levels emitted from aircraft engines. This research includes conducting laboratory experiments, with simplified hardware, at conditions high-speed aircraft would encounter in the stratosphere. Our program goal is to reduce NO$_x$ by approximately 90 percent. That transfers into an emissions index of from about 3 to 8. The emissions index is grams of NO$_x$ divided by one thousand grams of fuel consumed.

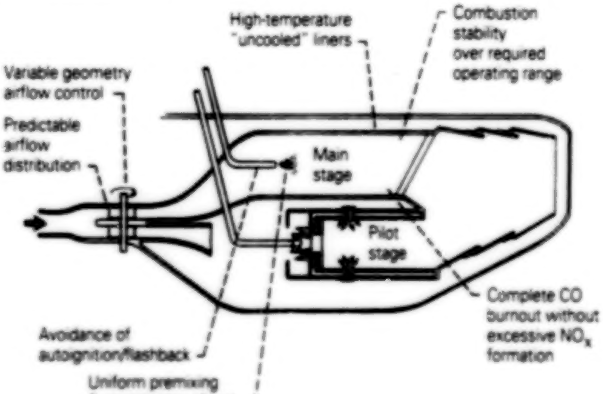
We've run tests with two concepts of ultra-low-NO$_x$ combustors: Lean-Premixed-Prevaporized—LPP for short—and Rich-Burn, Quick-Quench, Lean-Burn, or RQL.

The LPP combustor mixes fuel and air upstream of the burning zone and allows sufficient time for the liquid fuel to vaporize completely prior to entering the combustion system. This mixture—ideally, vaporized fuel and air perfectly blended—then enters the combustion system and burning takes place downstream of a flame stabilizer where the velocities are somewhat lower.

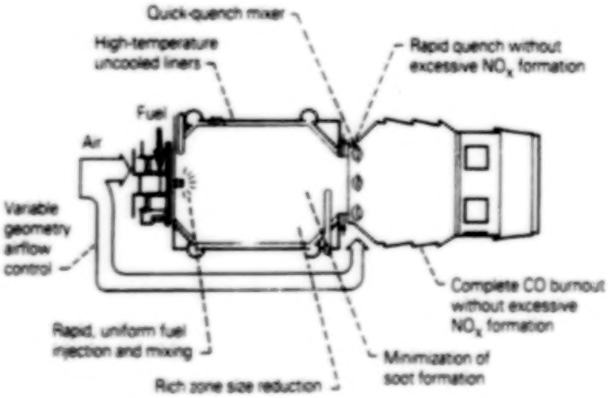
That in itself is a very simple process, but it is fraught with several potential problems. Since there is a combustible mixture upstream of the combustion zone, there is always the possibility that flame could flash back and damage the engine. That's a difficulty our research is attempting to eliminate.

Another challenge is that combustors are required to operate in a very wide range of conditions: Taxi/idle and altitude relight require operation at very low temperatures and pressures; takeoff and cruise require operation at very high pressures and temperatures. A positive feature of the LPP concept is that little if any soot will be produced. Soot may also present environmental problems in the stratosphere.

LPP Combustors


High-temperature "uncooled" liners
Combustion stability over required operating range
Variable geometry airflow control
Predictable airflow distribution
Main stage
Pilot stage
Complete CO burnout without excessive NO$_x$ formation
Avoidance of autoignition/flashback
Uniform premixing & vaporization of fuel

RQL Combustors


Quick-quench mixer
High-temperature uncooled liners
Rapid quench without excessive NO$_x$ formation
Fuel
Air
Variable geometry airflow control
Complete CO burnout without excessive NO$_x$ formation
Rapid, uniform fuel injection and mixing
Minimization of soot formation
Rich zone size reduction

When the fuel and air combine to produce a perfect homogeneous mixture, the ability to operate over wide ranges is very much reduced. An LPP system most likely has to be part of a system that incorporates another burner, probably in a parallel staged configuration.

An RQL system is more difficult to optimize in initial, fundamental experiments. It has two burning zones. In the first, excess fuel is put into a relatively small amount of air. Reactions occur in this very rich environment. That causes the chemistry to take certain paths which do not produce NO$_x$. Downstream, air has to be added to complete the reactions. This has to be done quickly and uniformly to minimize any additional NO$_x$ formation. And that is what's difficult to do. There is also a final burnout stage, so the system is complex.

Another problem exists in the rich-burn section: You cannot add additional air to cool the walls of the combustion system internally. So advanced high-temperature materials are a critical need for the area.

Our LPP experiments here at Lewis have produced tremendously encouraging results. We've indicated we can get down to NO$_x$ levels within our objectives. RQL combustor experiments are not as far along. It has taken a little longer to set up for those, and the NO$_x$ results, while not quite as low as the LPP, are well within our program goals.

In terms of soot formation, we anticipate that RQL combustors probably will produce levels comparable to current engines: below the visible threshold, but by no means the very small concentrations an LPP would produce. On the other hand, from an operational safety standpoint, you wouldn't have a combustible mixture upstream of the burning zones.

So each concept has pluses and minuses. These tests, along with analytical studies we're doing now, will give us sufficient information to choose which of these combustion systems is going to be the prime concept by the end of FY 1992. ➤

TOMORROW'S ENGINES: A MATERIAL ISSUE

The sleek shape and jumbo-jet size of next-generation supersonic transports probably will make them the most visually impressive aircraft in the skies. One thing that observers won't see, however, is the new class of materials that will make the planes' engines fuel-efficient and compatible with the environment.

The powerplants will be some of the most complex structures ever used on commercial aircraft. They will place severe demands on the performance of their structural materials.

For example, both low-emissions combustor concepts that NASA is studying in the High-Speed Research Program preclude the internal cooling found in the combustors of today's aircraft. Similarly, a high-speed civil transport will have noise-suppressing exhaust nozzles that will be long and mechanically complex to reach the desired sound levels. They will require much lighter-weight, higher-temperature materials than those now available if the engines are to be economically practical.

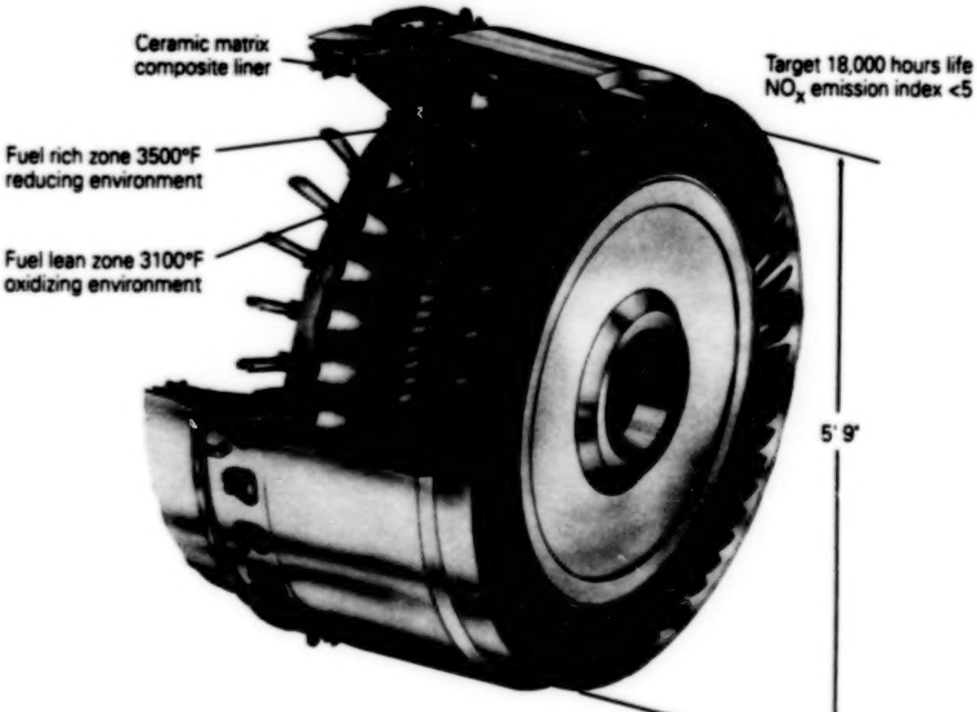
Advanced engine materials must meet a third criterion: durability. The useful life of commercial aircraft engines is typically measured in tens of thousands of flight hours. Studies have estimated that future supersonic transport powerplants must have an 18,000-hour service life to be economically feasible. . . and they would run 90 percent of that time near maximum operating temperatures!

NASA's Enabling Propulsion Materials (EPM) program is a major new FY 1992 initiative involving General Electric Aircraft Engines, Pratt & Whitney and NASA's Lewis Research Center. It is aimed squarely at the unprecedented technical challenges posed by supersonic transport engine requirements. The timing is right for the effort; the development and introduction of new materials normally take from 12 to 15 years.

Part of the EPM program focuses on ceramic matrix composites (CMCs) that could operate uncooled in the very high temperatures of low-emission jet engine combustors. Early work will focus on developing strong, small-diameter fibers that have thermal stability and creep resistance from 2375° to 3000° F. The program will eventually fabricate CMC components for proof testing.

EPM also will research intermetallic matrix composites (IMCs) for use in advanced noise-reducing nozzles. IMCs have a lower density than current superalloys and promise good resistance to oxidation at anticipated high-speed transport engine operating temperatures. But the thermal expansion difference between the matrix and fibers often limits their usefulness. This thermal mismatch will be a key research area in the Enabling Propulsion Materials program.

Composites offer potential strength-to-weight improvements of 30-40 percent compared with today's superalloys. They also promise significant benefits in structural weight reduction: For every one-pound decrease in engine weight, the gross weight of a next-generation supersonic airliner would drop by nearly 16 pounds. ➤


Ceramic matrix composite liner
Target 18,000 hours life
NOx emission index <5
Fuel rich zone 3500°F reducing environment
Fuel lean zone 3100°F oxidizing environment
5' 9"

The "Rich-Burn, Quick-Quench, Lean-Burn" combustor concept would require ceramic matrix materials able to operate for 18,000 hours at temperatures up to 3000° F.

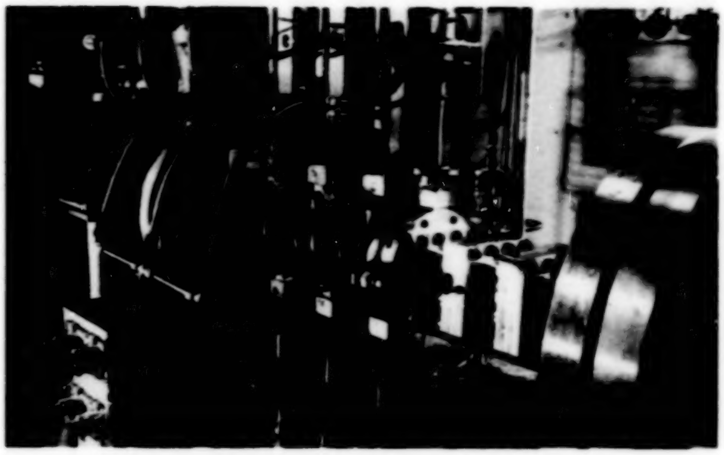
TECHNOLOGY ADVANCES TO PROTECT THE ENVIRONMENT

The most critical technology area in NASA's High-Speed Research Program focuses on advanced combustion concepts to reduce NO_x emissions from aircraft engines. This effort involves laboratory experiments using sophisticated instruments to study and develop burning processes that will control combustion byproducts. The goal: Cut NO_x emissions by 90 percent.

The key is to burn the fuel in a way that avoids excessive flame temperatures, which produce NO_x at a high rate. NASA is performing laboratory tests on two especially promising low-emissions concepts. The Lean-Premixed-Prevaporized (LPP) combustor (combustion chamber) mixes fuel and air upstream of the burning zone and allows sufficient time for the liquid fuel to vaporize completely. The mix of fuel and air then enters the combustion system and ignites downstream of a flame stabilizer where the flow velocity is somewhat slower.

The Rich-Burn, Quick-Quench, Lean-Burn (RQL) concept has two combustion stages. In the first, excess fuel is put into a small amount of air; this "rich burn" environment generates chemical reactions that minimize NO_x formation. Downstream, air is added quickly and uniformly and combustion is completed in a final fuel-lean stage.

The goal of noise reduction efforts in the High-Speed Research Program is to achieve noise impacts comparable to the FAA FAR 36-Stage 3 regulation—the current rule for new subsonic aircraft. In preliminary tests at Lewis and at a Boeing research facility, acoustic evaluations of small mixer-ejector nozzle models have reduced jet noise by 12-18 dB.



Flame tube rig at Lewis Research Center has tested the Lean-Premixed-Prevaporized (LPP) engine concept. The goal is to decrease NO_x emissions to less than 8 grams per kilogram of fuel burned.

Engineers at NASA's Langley Research Center have also evaluated a series of generic subscale nozzle configurations that have many features tested at Lewis and in industry. Researchers made diagnostic measurements to understand better the physics of each configuration.

THE SONIC BOOM CHALLENGE

It's a fact: supersonic transports create a sonic boom. Over water on transoceanic air routes, shock waves generated during supersonic flight pose little problem. But the plane's economic viability would be enhanced if sonic boom levels could be reduced to a level that makes overland flight possible.

One part of NASA's research in this area deals with the boom noise that would be acceptable to people living beneath the flight path. Since 1989, Langley has used a sonic boom simulator to test human response to the booms' acoustic energy under controlled conditions. Volunteer test subjects sit in an enclosure lined with sound-absorbing foam while large loudspeakers mounted in the door emit low-frequency noise. The Langley tests simulate a wide range of potential boom signatures that have been shaped by the careful design of supersonic transport concepts to minimize ground noise levels. The results so far show that "boom shaping" is a promising approach that may make overland supersonic flight possible.

The shaping of the wing and fuselage of a supersonic transport to reduce boom levels is a complex aerodynamic task. In 1990, NASA began a series of wind tunnel tests at Langley and Ames Research Centers to evaluate low-boom configurations. Two 1:300 scale models are being studied; unlike earlier HSCT models, they have realistic airplane features such as flow-through engine nacelles.

The miniature aircraft are nearly three times larger than any previous boom models, so researchers expect the models to yield greater accuracy than those studied in prior tunnel evaluations.

SUPERSONIC LAMINAR FLOW CONTROL

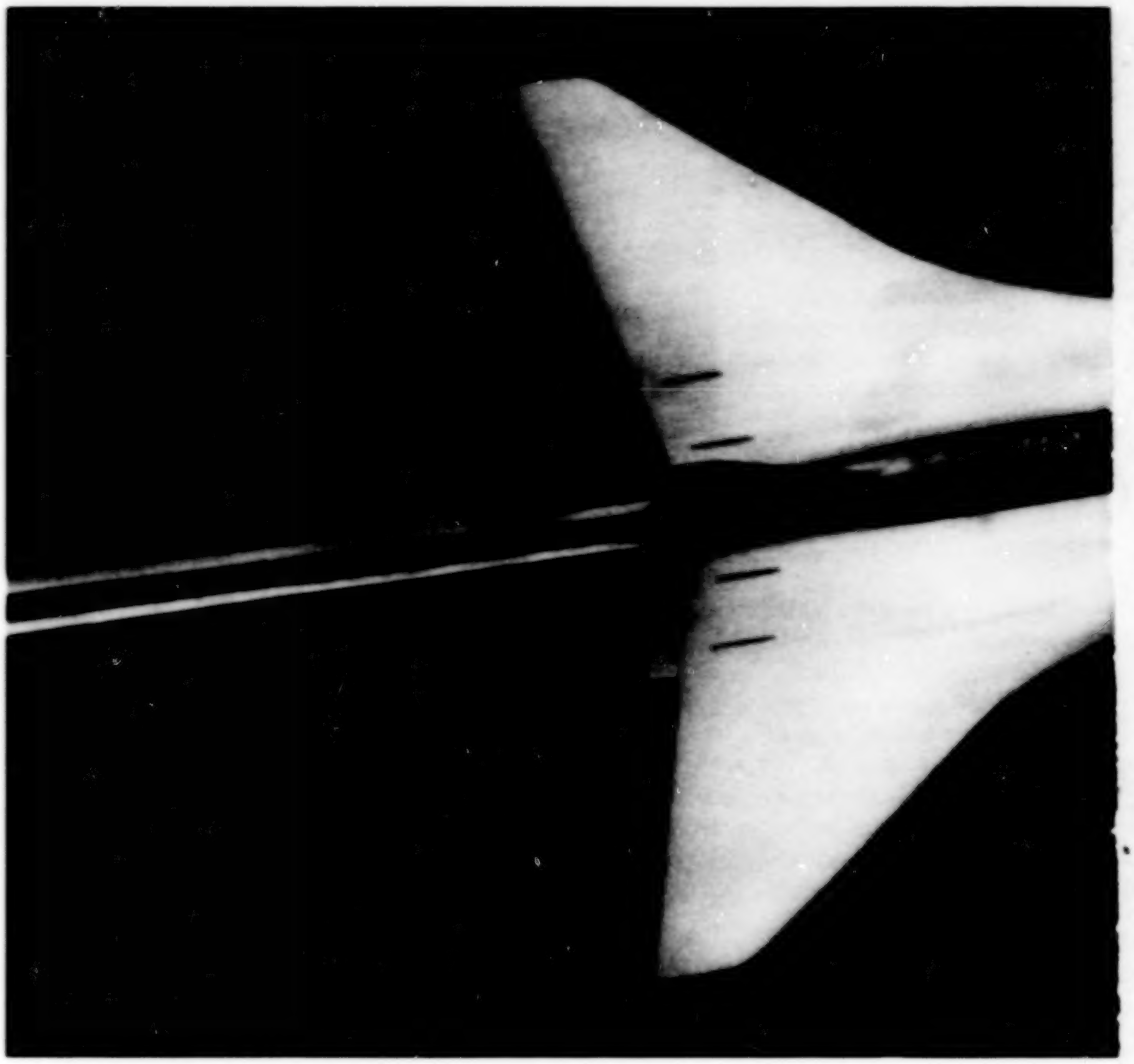
A supersonic transport zooming though the atmosphere at twice the speed of sound is extremely sensitive to aerodynamic drag generated by air friction on the airplane's skin. One way to reduce drag—and increase an aircraft's fuel efficiency—is to siphon off the turbulent airflow over the wings to produce smooth or "laminar" flow.

ORIGINAL PAGE
COLOR PHOTOGRAPH

NASA is testing the first experimental wing surface designed to improve laminar flow at supersonic speeds on two F-16XL research aircraft at Ames-Dryden Flight Research Facility. The "XL" is a delta-winged derivative of the General Dynamics F-16 fighter in service around the world.

The single-seat F-16XL #1 has a test surface, or "glove," fitted to its left wing. A suction system draws turbulent surface air through millions of tiny laser-cut holes in the test section. The outcome: improved laminar airflow over that part of the wing.

Researchers expect the flight experiments to validate computer codes that will aid the design of future supersonic airliners. The second F-16XL, a two-seat version, is now being modified with a slightly different type of laminar flow test section that more closely represents the apparatus that could be mounted on a high-speed civil transport.



THE OUTLOOK FOR HIGH-SPEED TRANSPORTATION

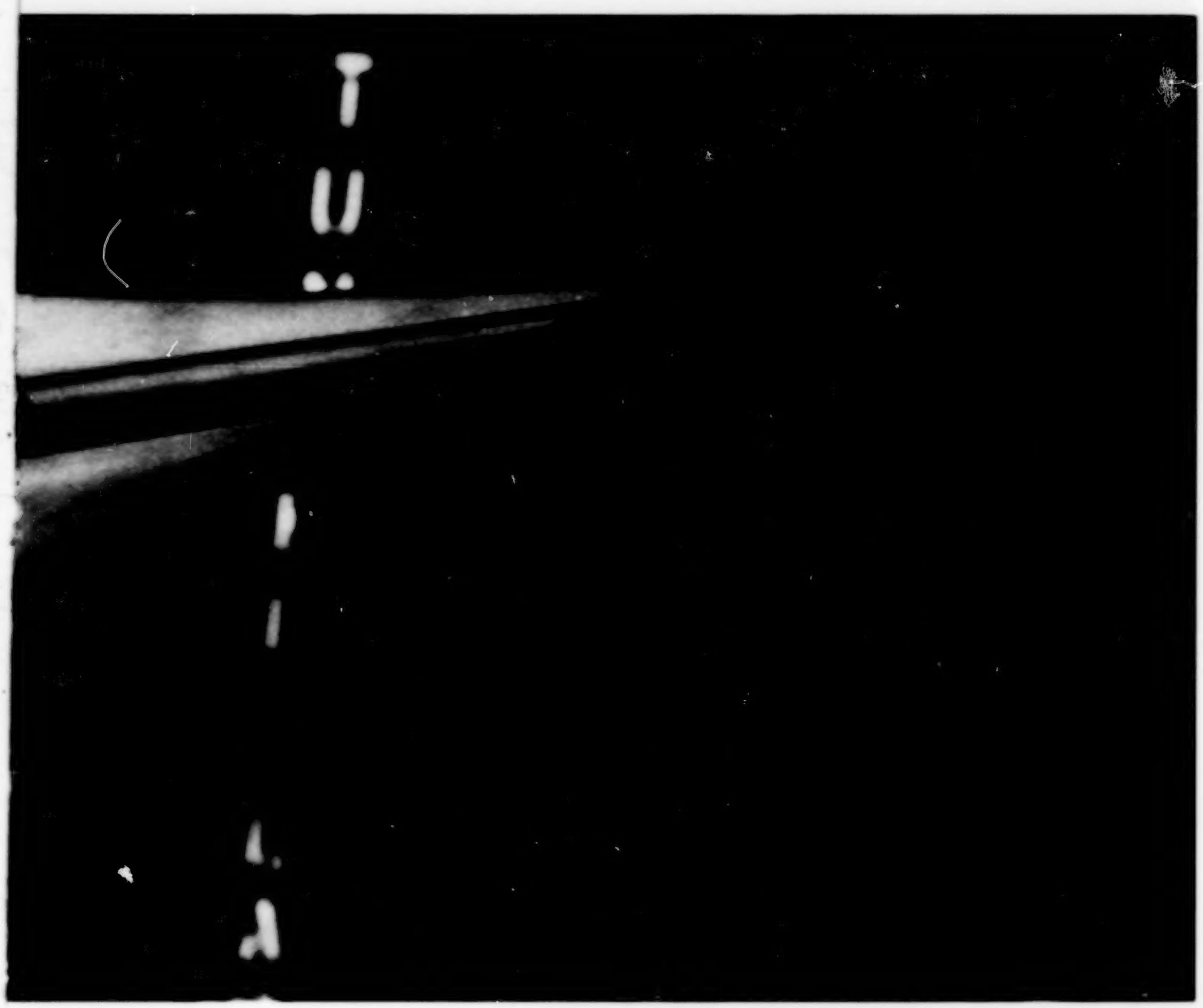
Developing a high-speed civil transport will be an expensive proposition for the American aerospace industry. There may, in fact, be some international cooperation to improve the chances of commercial success.

But this won't diminish the battle for leadership in such a venture considering the potential multibillion dollar market at stake. The agency is committed to helping its industry partners protect sensitive information that could affect U.S. competitiveness in the high-speed marketplace of the future.

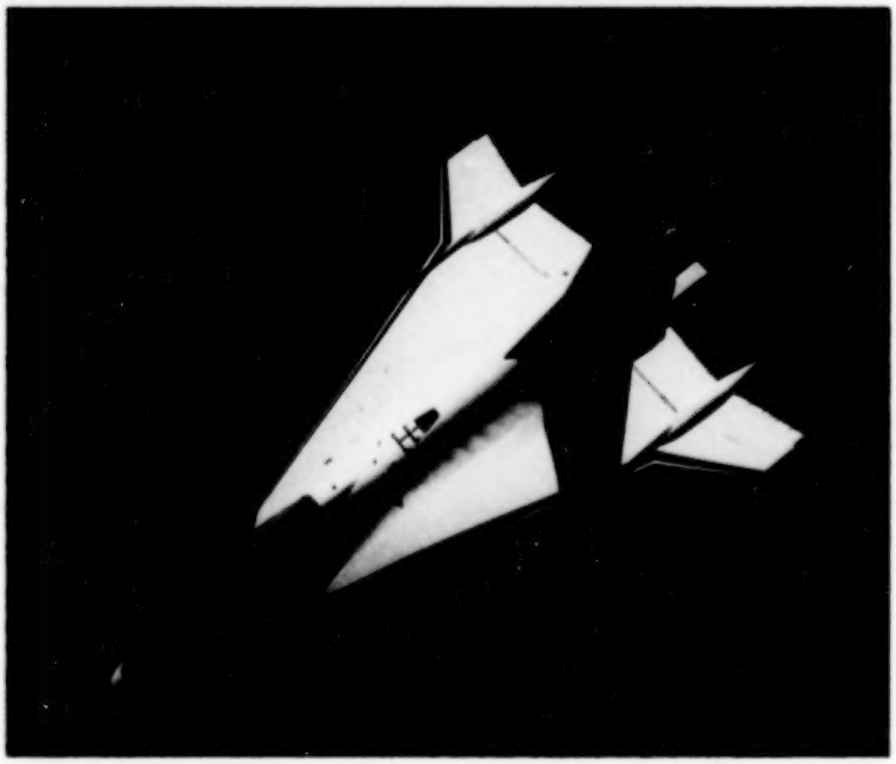
The High-Speed Research Program is the cornerstone of NASA's aeronautics program for the 1990s. The environmental and technology issues are extremely challenging, but the agency has committed some of its most advanced test facilities—and some of its best people—to the task.

Assuming the program continues to progress and no insurmountable environmental barriers to a supersonic transport fleet arise, the next step would be a NASA/industry technology development effort focused more on possible vehicles. It would provide a technical foundation that the nation's aerospace companies can use to make sound business decisions about airframe and engine programs.

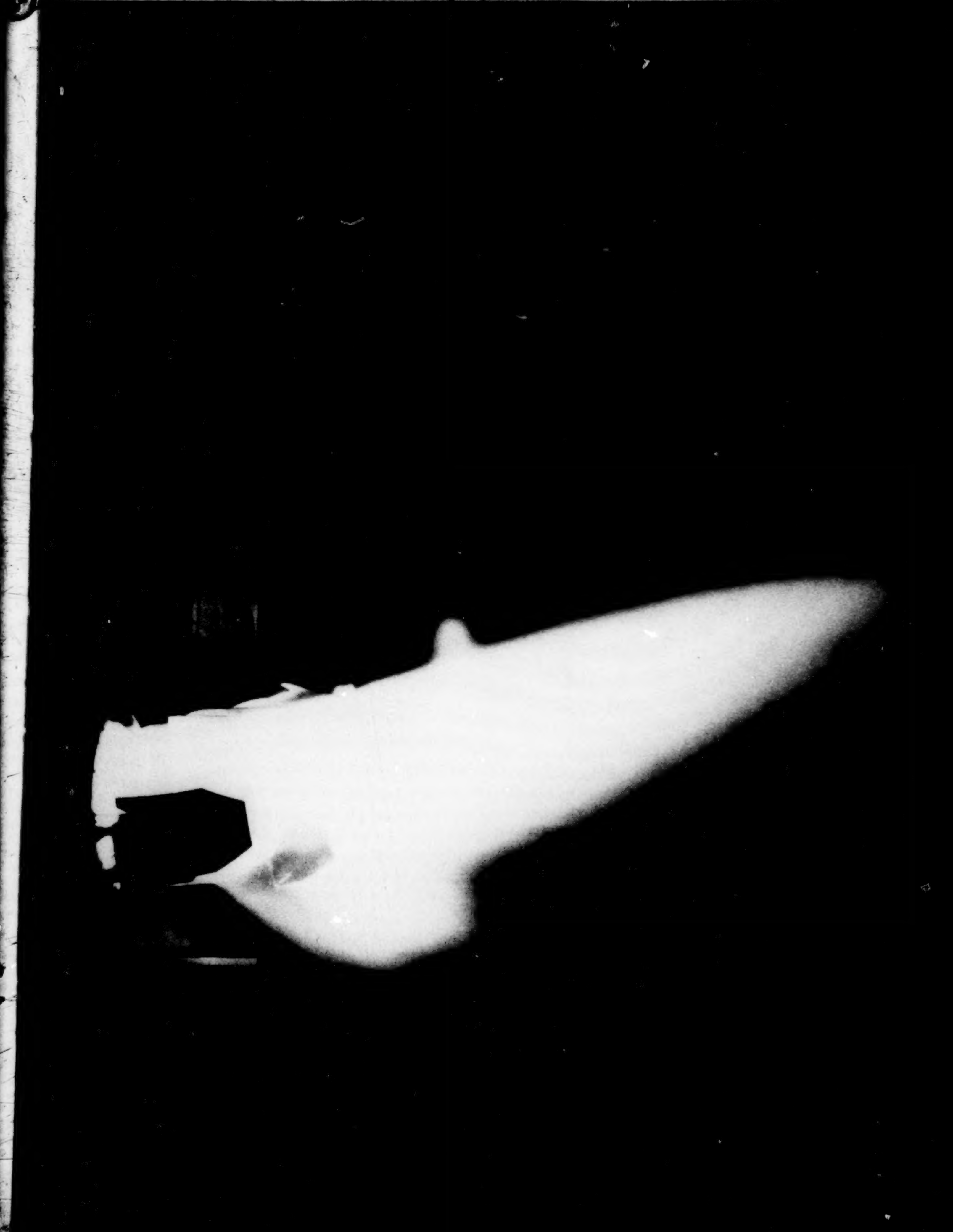
With that technology in hand by the end of this decade, the first American-made supersonic airliner could roll out of the hangar by the year 2005—and a new chapter in the history of air transportation will have begun. ➤



1:300-scale model in Langley's Unitary Plan Wind Tunnel has long fuselage and slender forebody typical of low-boom high-speed civil transport configurations.



NASA selected the F-16XL for supersonic laminar flow control (LFC) studies because its wing shape approximates that proposed for a next-generation supersonic transport. The two-seat aircraft shown here will be fitted with an LFC glove for future tests.



Building on its NACA heritage, NASA aeronautics research on high-performance aircraft has always been closely linked with similar efforts in industry and the Department of Defense. Often the agency's programs address problems in performance or capabilities that face existing military aircraft. Just as frequently, that responsibility is mixed with the exciting challenge of researching and developing new technology to ensure American pilots fly the best aircraft in the world.

Of course, technological advances in high-performance aircraft don't happen in a vacuum. The results of NASA's research in this vital national area frequently can be applied to other classes of aerospace vehicles, both military and civilian.

NASA's recent research in the high-performance arena has had outstanding success in several important areas:

- High-alpha flight
- Technology to enhance the maneuverability of high-performance aircraft
- Technology to increase military aircraft survival and performance
- Supersonic STOVL (Short Take Off and Vertical Landing) aircraft
- Advanced rotorcraft technology

X-29 forward-swept-wing research aircraft in high angle-of-attack flight.

PREPARING TECHNOLOGY OPTIONS FOR FUTURE HIGH–PERFORMANCE AIRCRAFT AND ROTORCRAFT

HIGH-ALPHA RESEARCH PROGRAM

Angle-of-attack is the tilt of a plane's body and wings relative to its direction of flight. A pilot's ability to control an aircraft at high angles-of-attack (also called "high alpha" by engineers) may be an advantage in air-to-air combat. But the high-alpha regime poses unique and difficult challenges to aerodynamicists' understanding of what happens to a plane at such angles-of-attack.

Since 1987, NASA has been conducting an aggressive high-alpha research program. The effort involves supercomputers that perform computational fluid dynamics (CFD) simulations, wind tunnel tests, runs in flight simulators and research aircraft tests.

In the last two years, NASA's research has focused on gathering data in flights by a specially modified F/A-18 High-Alpha Research Vehicle (HARV) based at NASA's Ames-Dryden Flight Research Facility. In turn, that information refines CFD codes and validates continuing wind tunnel tests.

For example, in mid-1991 NASA began testing an actual F/A-18 in the giant 80x120-foot section of Ames Research Center's National Full-Scale Aerodynamics Facility. The wind tunnel studies are designed to correlate data from small-scale tunnel tests and the F/A-18 HARV missions.

The Ames investigations also will develop a data base on forebody flow control, that is, using devices to modify the airflow around a plane's nose; researchers believe forebody flow control techniques can increase an aircraft's controllability in high-alpha flight. A third purpose of the tunnel tests is to study the aerodynamic tail buffeting experienced by twin-tailed fighters such as the F/A-18.

X-29

Tests with the second of two X-29 research aircraft also looked at the high-alpha regime, but for different reasons. The X-29 investigated the high angle-of-attack characteristics and military utility of its unique forward-swept-wing/canard shape.

There were attempts to come up with practical forward-swept-wing military aircraft as long ago as World War II. But not until the arrival of composite materials in the 1970s could engineers design a wing that had sufficient aeroelasticity to withstand the stresses imposed by forward sweep.

Grumman Aircraft Corporation built two X-29s under a contract with the Defense Advanced Research Projects Agency (DARPA). The first aircraft flew in December 1984, the second in May 1989. The #1 X-29 validated predictions about the performance of the forward-swept-wing concept in 242 flights through December 1988—a record for any X-series plane at Ames-Dryden.

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HIGH ALPHA FLIGHT RESEARCH

SINCE 1987, NASA HAS USED A SPECIALLY MODIFIED F/A-18 HORNET TO EXPLORE THE IN-FLIGHT PERFORMANCE OF A MODERN AIRCRAFT DESIGN AT HIGH ANGLES-OF-ATTACK. JENNIFER BAER-RIEDHART AT AMES-DRYDEN FLIGHT RESEARCH FACILITY, THE AIRCRAFT'S HOME BASE, EXPLAINS WHY THE CONTINUING PROGRAM OF FLIGHT TESTS IS SO IMPORTANT.

➤

Wind tunnel tests and computer simulations give us a good approximation of a plane's high-alpha characteristics. But it's very hard to duplicate the atmospheric conditions and the aircraft's dynamic response in that regime on the ground. There are also differences of scale in the airflows. So we still need to fly the F/A-18 High-Alpha Research Vehicle to verify our previous calculations and gather data that help us refine those computational models.

In the first phase of flights, from April 1987 to September 1990, we got a tremendous amount of information about the basic aerodynamics of the F/A-18 aircraft at angles-of-attack up to 55 degrees. The airplane was highly instrumented with pressure orifices on its surface. We also visualized the airflows with dyes and smoke emissions. Up to 55 degrees, we now know the airplane very well; it's fairly maneuverable and easy to operate.

When we started the program, the computational fluid dynamics (CFD) work for high-alpha conditions was pretty much nonexistent. One significant result of the flight tests is that we've now developed a good CFD code for the aircraft itself, so that we can model its response at even higher angles-of-attack.

In the second phase of flight tests, which started in 1991, we mounted thrust vectoring vanes around the exhaust nozzles of the F/A-18's engines. The advantage of thrust vectoring is that it gives us control we don't have with the aerodynamic surfaces alone at high angles-of-attack. It also gives us additional control of the aircraft itself even at lower angles-of-attack.

In 1991 and 1992, we are expanding the flight envelope beyond 55 degrees alpha and the current 25 degrees per second yaw rate using the thrust vectoring vanes. We hope to get actual research data on the aircraft. The ultimate goal is to get up to 70 degrees alpha in stabilized flight and see what happens to the flow at that very high angle-of-attack.

After the thrust vectoring flights, the next step will be to look at forebody controls: using tangential blowing and mechanical devices to modify the airflow around the nose of the F/A-18. These are much lighter installations than the thrust vectoring system and they're what we call "nonintrusive." There's no hardware on the back of the airplane to intrude on the exhaust and cause a loss of power when the thrust is vectored.

Also, the center of gravity in newer aircraft is such that the forebody moment arm is much longer compared to older types. We don't need much of a push up front to get a lot of controllability out of it.

From NASA's standpoint, we're trying to provide a data base, the codes and tools that industry can use. Eventually, we hope that engineers will be able to go into the CFD codes that have been established to look at the high-alpha characteristics of advanced aircraft designs. They may be able to build a single wind tunnel model rather than putting a lot of money and effort into extensive tunnel and flight test work. Designers should also be able to do tradeoff studies and analysis work before they cut metal. ➤

F/A-18 High-Alpha Research Vehicle with thrust-vectoring system.

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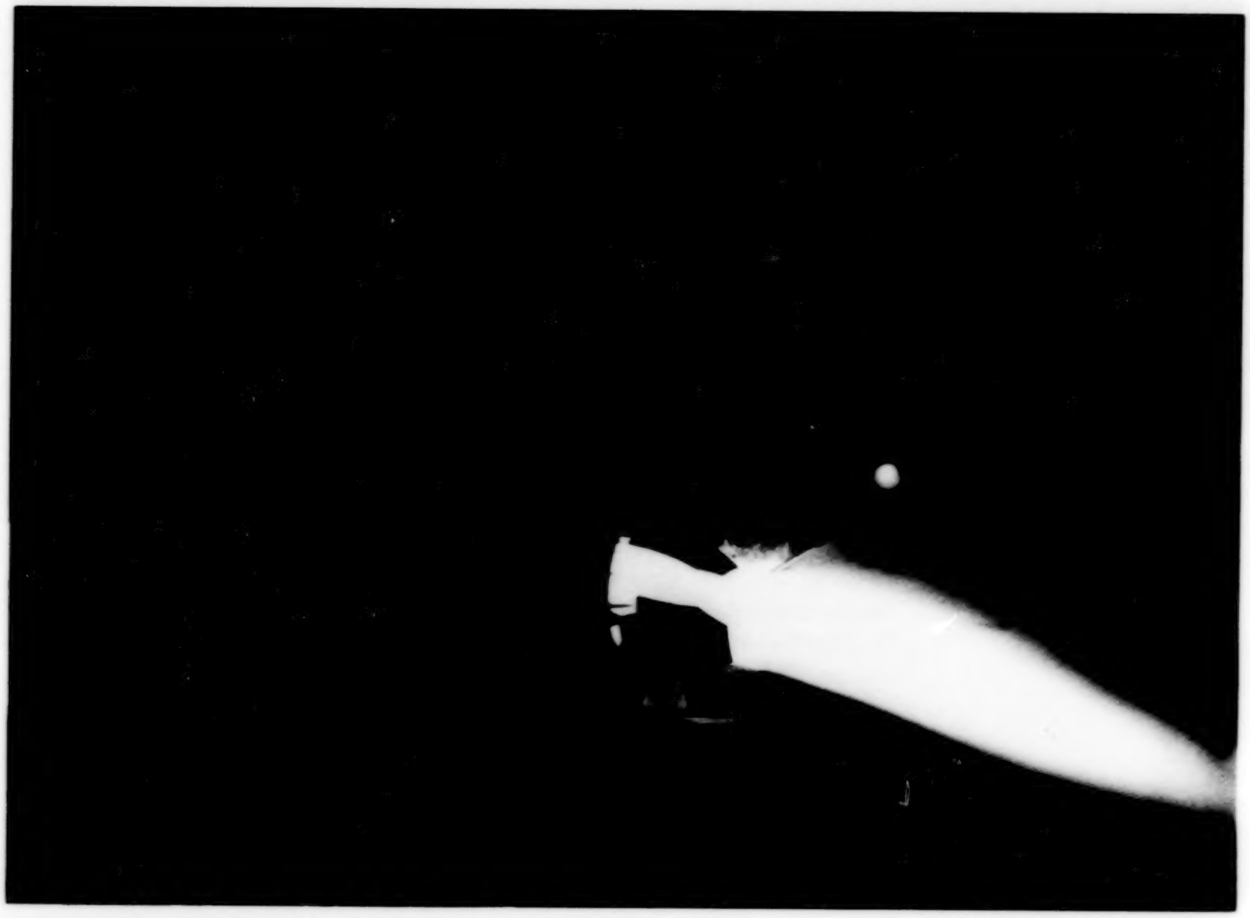

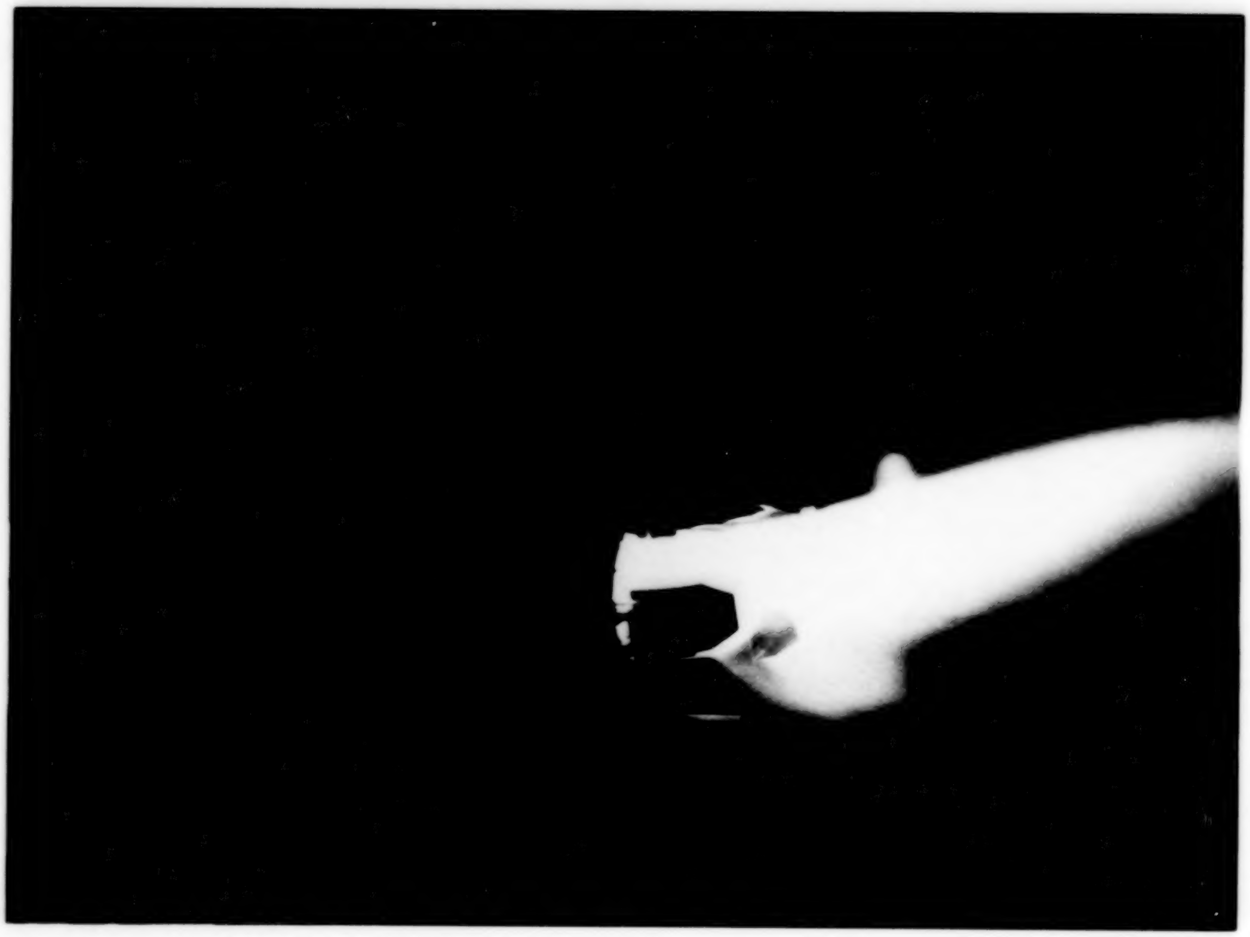

Early-morning "hot tests" on the F/A-18 HARV show exhaust plume deflection by thrust-vectoring paddle vanes. Inconel steel paddles can withstand temperatures up to 2000° F.

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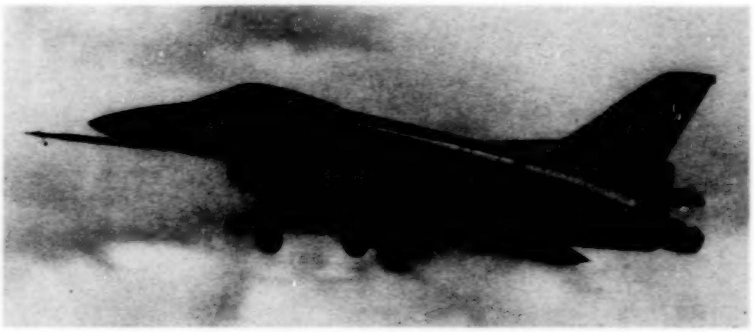
The #2 X-29 began a series of high-alpha investigations late in 1989. The plane was equipped with an antispin parachute system, and its computers were loaded with new flight control laws derived from flight tests of a 22-percent-scale drop model at NASA's Langley Research Center.



NASA, Air Force and Grumman pilots have found that the X-29 has better controllability in the high-alpha regime than computer simulations and wind tunnel tests had predicted. Interestingly, the X-29 handles well in high-alpha flight without leading edge slats for more lift and thrust vectoring vanes to change the direction of its exhaust. Both devices increase stability and control at high angles-of-attack.

NASA assumed responsibility for flight research with the X-31 at the end of 1991.

THE FUTURE OF NASA'S HIGH-ALPHA RESEARCH

NASA has agreed to assume responsibility for flight tests of the X-31 research aircraft from the Department of Defense. The X-31, built by Rockwell International and the German firm Messerschmitt-Bolkow-Blohm (MBB), is designed to demonstrate post-stall controllability and the combat uses of good high-alpha maneuverability. The plane will join the other high-alpha research aircraft at Ames-Dryden.

INCREASED MANEUVERABILITY

Supersonic aircraft usually have highly swept wings with sharp leading edges. At lower speeds, however, airflow over the wings separates and forms vortices over the wings' upper surface. The result: a slight increase in lift, but a significant penalty in drag.

In 1991, Langley Research Center completed the Vortex Flap program, an important effort to improve the aerodynamic performance of supersonic aircraft at transonic and subsonic speeds. Through CFD simulations and wind tunnel tests, Langley researchers developed a carefully shaped flap that traps a tornado-like swirl of air called a vortex. The goal was to increase lift-to-drag ratio.

WHY HIGH ALPHA?

Although the United States dominated the skies in the Gulf War, it doesn't pay to be complacent. Somewhere ... someday ... American fighter pilots may have to engage a well-trained enemy air force ready and willing to use high-tech aircraft and weapons.

NASA's research on how aircraft perform in high angle-of-attack ("high-alpha") flight is aimed squarely at building a data base that industry can use to design superior military fighters.

In air-to-air combat, a victorious pilot is usually flying a more maneuverable—not necessarily faster—aircraft than his adversary. A full-blown dogfight can cover miles of airspace and involve many high-g turns and loops. That's where superior performance in high-alpha flight may be a decisive factor.

The high-alpha regime (greater than about 55 degrees angle-of-attack) is an unfriendly place for most of today's high-performance aircraft. As a plane increases its "alpha," the wings start to rock; one wing drops, gets a bit of lift and comes back, dropping the other wing. Air stops flowing over the wings and the plane stalls, literally falling out of the sky.

The effect on combat capability is significant. A pilot must make wider turns and loops because he can't pull the plane up any higher than the 55-degree limit. If he does and the plane stalls, an adversary may seize the advantage and attack.

An aircraft with good high-alpha handling characteristics can reduce the time a pilot needs to maneuver into position to fire at the enemy. For example, he could pitch the plane's nose up to 70 degrees angle-of-attack in level flight, almost stopping in mid-air. Using the flight controls, he could kick the aircraft around, point at the adversary and shoot.

Exceptional high-alpha performance also lets a fighter turn corners more quickly because the pilot can roll the plane about the vector axis and go back the way he came. And there's a bonus: high-alpha turns normally put less stress on the aircraft, resulting in a longer usable service life.

NASA researchers are feeding the results of high-alpha wind tunnel tests and flight research back into computational fluid dynamics (CFD) computer codes that are used to predict aerodynamic performance. The goal, of course, is to make the CFD codes reflect as accurately as possible what will happen to a plane in the high-alpha regime.

Eventually, industry will be able to run computer simulations in many instances as an alternative to wind tunnel tests. They'll also be able to do tradeoff studies before the company ever "bends metal": How maneuverable should the plane be for its particular mission? How much high-alpha capability can be designed into the aircraft for a specific cost limit?

CFD predictions will never completely replace flight tests because of scaling effects. But thanks to NASA's research, the designers of future prototype aircraft can be confident that they know their plane's high-alpha performance before the prototype ever takes wing. ➤

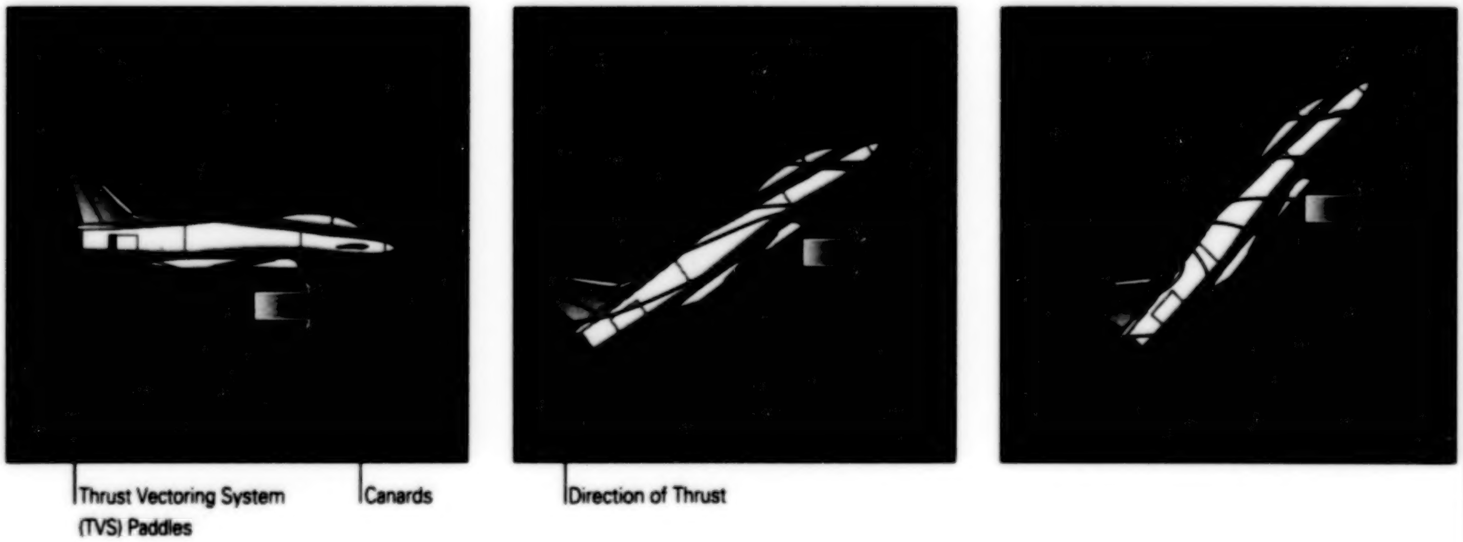
NASA selected its veteran F-106B research aircraft at Langley to validate the vortex flap concept. The 106's swept-back delta wing planform was considered representative of aircraft that might benefit from the design. The plane's wing leading edges were removed and replaced with vortex flaps that could be adjusted for different test conditions before takeoff. The right wing was mounted with surface pressure instruments. The left wing was equipped with accelerometers and strain gauges to monitor structural loads and deformation.

The F-106B made 93 vortex flap research flights from August 1988 to February 1991; engineers checked the aerodynamic performance of the flap and mapped the airflow for selected flap deflection angles. The tests proved that the vortex flap does have significant performance benefits, and answered aerodynamicists' questions about its impact on handling qualities and flight characteristics of a supersonic aircraft. The results will apply to future supersonic military and civilian aircraft.

F-106B vortex flap research model in Langley Research Center's 7x10-foot High Speed Tunnel. Downward-pointing flap traps a vortex spanwise across its leading edge.

INTEGRATED CONTROLS = BETTER SURVIVABILITY AND PERFORMANCE

Flying today's fighter and attack aircraft puts a heavy workload on the pilot. There are throttle setting changes to make, engine temperatures to watch and fuel usage to monitor. If one of the plane's flight control surfaces fails or is damaged in combat, the pilot often has his hands full just to keep the plane in the air.



In level flight (left), an aircraft specially equipped for high-alpha maneuvers doesn't need to use its canards (small wings on the forward fuselage) or its thrust vectoring system (TVS) paddles. As the aircraft pitches up and continues forward (center), the airflow starts to separate from the nose; the canards and paddles automatically deflect to keep the plane under control. At about 70 degrees angle-of-attack (right), airflow separation from the nose and upper wing surfaces increases but the canards and thrust vectoring system maintain the desired attitude. The TVS also lets the pilot yaw the aircraft around in high-alpha flight to point the nose at an adversary.

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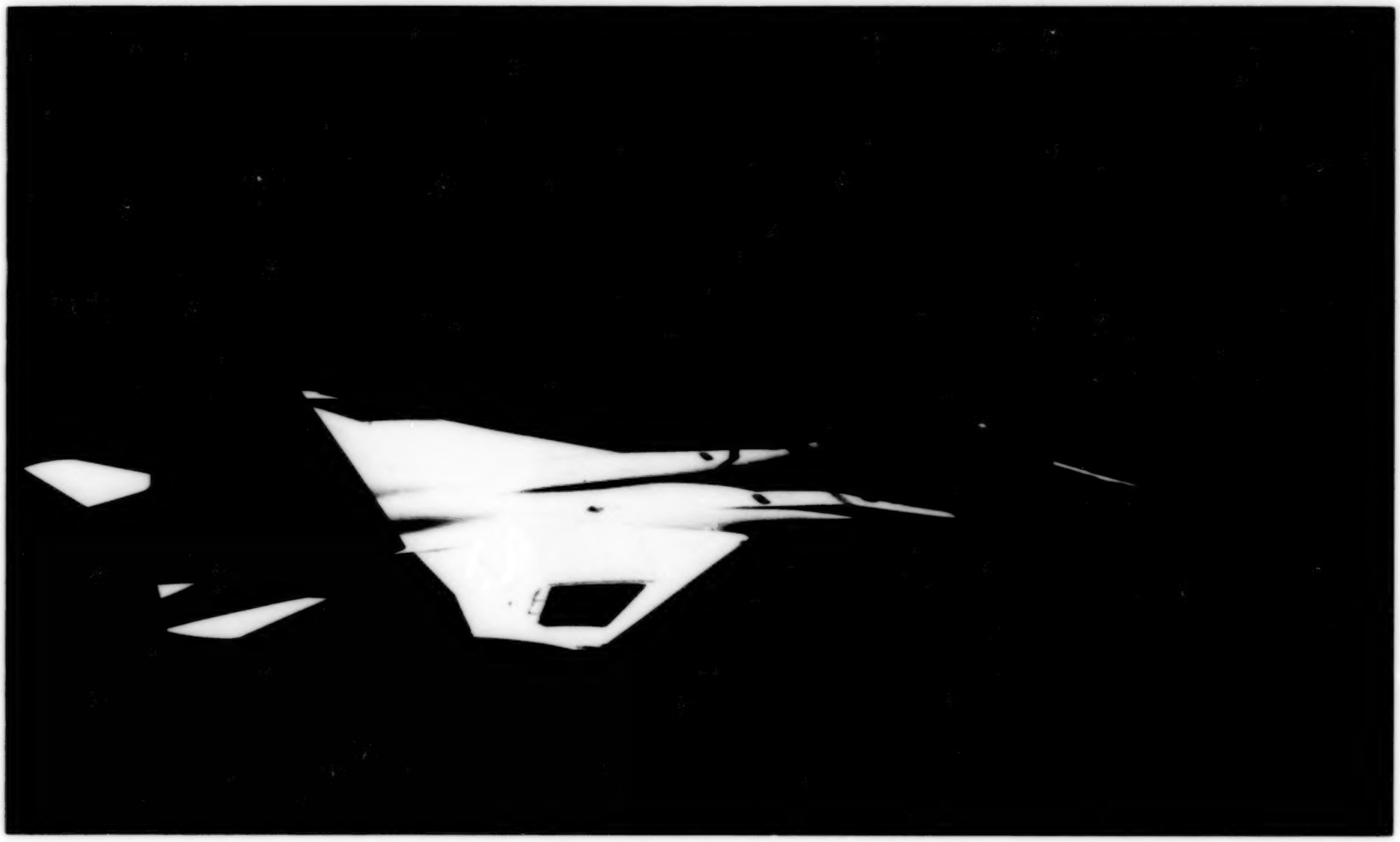

NASA F-15 is testing its Performance Seeking Control (PSC) system. PSC uses integrated control laws to ensure that peak engine and maneuvering performance is always available regardless of the mission or immediate needs.

During late 1989 and early 1990, NASA investigated what may ultimately be a major breakthrough in airborne flight control capability: the Self-Repairing Flight Control System (SRFCS). The program, sponsored by the U.S. Air Force, proved the ability of a flight control system to identify a failed component, isolate it and reconfigure the ailerons, rudders, elevators and flaps to continue the aircraft's mission or let the pilot land safely.

When the system sensed a failure, it selected the best precomputed solution from a set of control laws loaded into the F-15's flight computer. A display in the cockpit informed the pilot of the control surface reconfiguration and displayed resulting operational limits such as reduced "g" loading, angle-of-attack maneuvering restraints or decreased airspeed and altitude margins.

SRFCS also could monitor aircraft subsystems, which allowed the system to diagnose and identify failures that could be hard to repeat and isolate during postflight maintenance.

An advanced self-repairing system must be thoroughly tested before the technology is used in future aircraft designs or retrofitted to existing aircraft. The envelope of an operational SRFCS could include landing tasks, supersonic speeds and automatic terrain-avoidance and terrain-following modes.

Besides NASA and the Air Force, McDonnell Aircraft Company and General Electric's Aircraft Control Systems Division also participated in the SRFCS research.

PERFORMANCE SEEKING CONTROL

The F-15 began a program called Performance Seeking Control (PSC) in mid-1990 to optimize total aircraft engine performance during steady-state engine operations. The system is linked with the plane's digital flight control, inlet control and engine control systems.

Flight tests have shown that PSC decreases fuel use in cruise conditions and maximizes excess thrust during accelerations, climbs and dashes. It also may extend engine life by reducing the fan turbine inlet temperature.

NASA's PSC research includes developing methods in the digital engine control system to detect component degradation. This information, coupled with normal preventive maintenance, will help ensure fail-safe propulsion systems in high-performance aircraft of the future.

Performance seeking control systems apply to a variety of aircraft. Planes with thrust vectoring propulsion systems—where flight and engine control integration is essential—would benefit most. PSC also could find its way aboard supersonic cruise transport aircraft and transatmospheric vehicles such as the National Aero-Space Plane (NASP), where large operating envelopes and a limited engine data base make engine trim functions difficult. Once developed, PSC systems may increase engine thrust to 15 percent and cut fuel consumption up to 20 percent.

PSC research flights with the NASA F-15 are expected to continue until early 1992.

NEW DATA SYSTEMS

Some of NASA's research to give U.S. aircraft better performance isn't dramatic, but it's no less important. For example, in 1991 the agency began evaluating a unique Optical Air Data System (OADS) that uses laser light instead of air pressure to give pilots airspeed and attitude information. DARPA sponsors the project.

The external tubing of standard air pressure systems disturbs the airflow over an aircraft. The openings also must be cleaned of insects and debris frequently to ensure accurate data collection. OADS, however, is entirely within the airframe of a NASA F-104 research aircraft at Ames-Dryden. The laser beams project through lenses and windows, so external maintenance is minimal. The system focuses two sheets of laser light ("sheet pairs") several feet away from the side of the aircraft. As microscopic particles pass between the beams, OADS measures their direction and speed and processes the data into standard airspeed and angle-of-attack displays.

A pilot prepares for a rotorcraft nap-of-the-Earth simulation in the Vertical Motion Simulator at NASA's Ames Research Center.

ROTORCRAFT TECHNOLOGY

In combat, helicopters must be able to penetrate enemy-held areas at low levels to avoid detection. The difficulty of flying close to the ground is magnified at night or during adverse weather. Pilots currently use terrain-following radar, forward-looking infrared (FLIR) systems and night vision goggles to help them in making low-level penetrations. But what if they had the benefit of a system that would automatically hug the terrain according to a preprogrammed digital map of the threat area—much like the vaunted Tomahawk cruise missiles did in the Gulf War?

That's the goal of NASA's Automated Nap-of-the-Earth (NOE) program, a low-altitude guidance concept that takes advantage of terrain knowledge to guide helicopter trajectories. Over the last few years, the basic computer algorithms and displays have been developed by researchers and tested by NASA, Army and Air Force pilots.

In 1990, NASA and the U.S. Army agreed to do a joint

SUPERSONIC STOVL: SHORT TAKEOFF VERTICAL LANDING

WHAT IF WE COULD TAKE THE COMBAT PROWESS OF AN F-16 OR AN F/A-18 FIGHTER AND GIVE IT THE ABILITY TO MAKE VERY SHORT TAKEOFFS AND VERTICAL LANDINGS? THAT'S BEEN THE THRUST OF NASA'S SUPERSONIC STOVL RESEARCH EFFORTS FOR NEARLY SIX YEARS. PETE BATTERTON OF NASA'S LEWIS RESEARCH CENTER RECAPS THE PROGRAM'S RECENT PROGRESS.

One of our primary efforts here at Lewis has been research on hot-gas ingestion. When an aircraft is doing a vertical landing, the jets exhaust downward, the exhaust reflects off the ground, then recirculates back up into the engine inlets. This causes either engine stability problems or a loss of performance.

We've been investigating the hot-gas ingestion phenomenon itself, looking at devices for deflecting the hot-gas away from the inlets and developing new facility techniques. In the past 18 months, we've installed a remote control model positioning system that can handle a full jet pressure ratio and temperatures up to 1000° F. We've also put in a laser light sheet full-visualization system to help us see where the hot-gas is going and see the whole field around the aircraft. We obtained excellent data from several runs in Lewis's 9x15 wind tunnel.

Ames Research Center also has done a lot of parallel small-scale ground effects work in terms of "fountain suckdown." When there are a number of jets impinging on the ground, the flow runs along the surface. If it runs together, it creates a fountain, that is, a reflection of the flow that reflects back up and pushes up on the bottom of the aircraft. The induced flow over the aircraft tends to create a negative pressure under the aircraft—hence the term "suckdown."

Another area in which we've made a lot of progress—though we're still waiting for the final proof of testing—is integrated controls. When a STOVL aircraft is coming in for a landing, the aerodynamic control surfaces are no longer effective because there's no air speed. So you're dependent on the aircraft's jets to provide attitude control; essentially the propulsion system is your flight control system.

We've been developing and extending some techniques called Design Methodology for Integrated Control Systems that were originally started by the Air Force. We're extending that type of design for the transition hover control problem, working this program jointly with NASA's Ames Research Center.

NASA recently completed the ejector augmentor program that we started with Canada several years ago. An ejector is a device that uses a small amount of high pressure (primary) air to move a large quantity of low pressure air, which is more efficient for hover. The program originally began at Ames; in fact, the full-scale General Dynamics E-7 model was built and successfully run in their 40x80 and 80x120 wind tunnels.

Lewis's role was to validate the ejector performance claimed by the Canadians. We evaluated both cold and hot primary jets and measured performance effects. In previous efforts with the ejectors, the process of going from scale models to full-scale ejectors just didn't work. This ejector performed very well and I think that the E-7 represents a fairly viable ejector augmentor configuration STOVL aircraft.

Lewis recently has begun a lot of work with

flight experiment of the NOE concept on an Army UH-60 Blackhawk helicopter. To prepare for the flight tests, NASA's Ames Research Center has done two detailed operational evaluations of the NOE algorithm in its Vertical Motion Simulator (VMS).

The first simulation was done in June 1990. Pilots flew typical missions using a UH-60 model, a helmet-mounted display and a terrain model of the Carlisle, Pennsylvania area where the actual flights will take place.

The second series of computer-generated flights includes an interface with a replica of the Blackhawk's flight computer. The tests are validating the flight software and are being used to develop a detailed flight test plan. Ames has also done studies of advanced high-speed rotorcraft concepts that could find their way into civil and military use. The work addresses technology issues such as drag and propulsion performance, acoustics, dynamics, materials and structures.

SHORT TAKEOFF/ VERTICAL LANDING (STOVL)

With its short-field takeoff and vertical landing ability, the AV-8B Harrier has been a stalwart of Marine Corps aviation for years, but it isn't designed to exceed the speed of sound.

Since the mid-1980s, NASA has been researching designs and technology that would give the nation's air forces a supersonic STOVL capability. A five-year joint STOVL effort between the United States and the United Kingdom ended officially in January 1991. Both countries worked on

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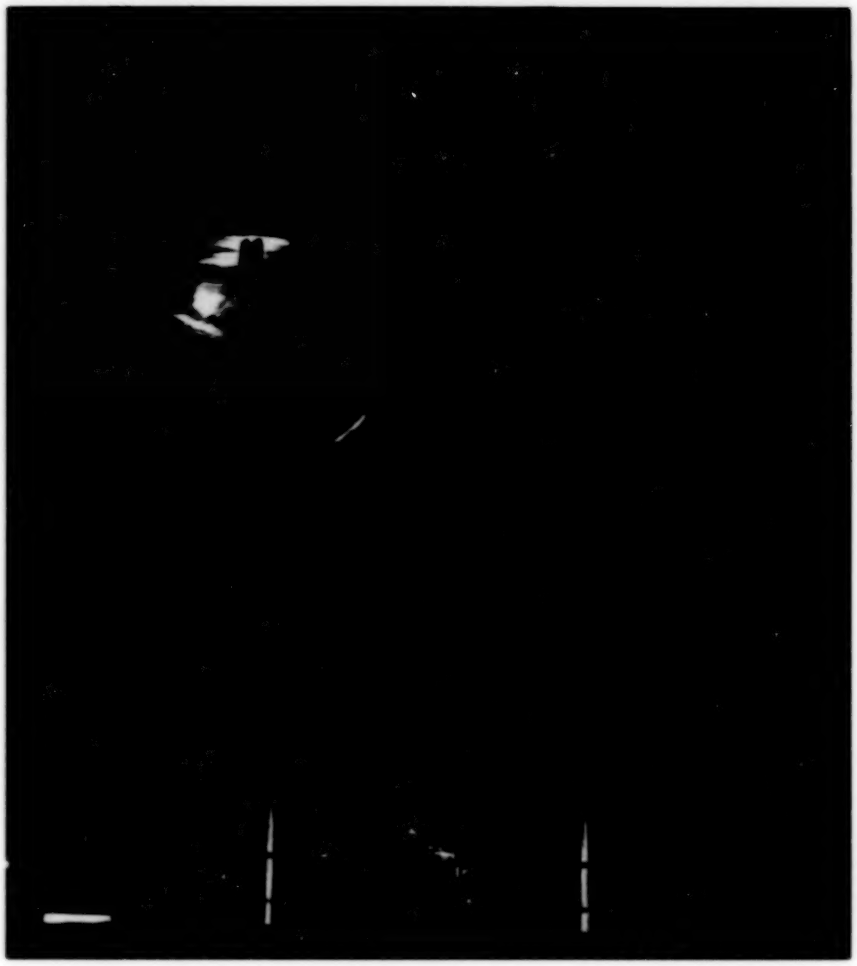
exhaust system scale models, looking at the flow properties and performance parameters for the vertical thrust nozzles themselves. These nozzles are required for a STOVL aircraft in a hover mode. CFD computer codes will be key to analyzing and designing the complex exhaust ducting used by most of the STOVL propulsion concepts. At Lewis, we're emphasizing the PARC 3-D (computer code) because of its excellent documentation and good reliability. We're working on internal flow parametrics with that code almost exclusively.

I think that NASA's supersonic STOVL work is really leading the way. We're trying to show the Department of Defense (DoD) that these problems are solvable now. When DoD defines their next fighter's requirements, they should consider whether they want to have the vertical landing capability or not.

That's NASA's ultimate goal: to provide that option for them. ➤



Laser illuminates exhaust from full-scale E-7 STOVL configuration at Ames Research Center.

common challenges such as integrated controls, ground effects, engine gas ingestion and the acoustic environment around potential aircraft designs.

As intended, the research did not zero in on any one propulsion concept, but determined the strengths and weaknesses of four different systems:

- Ejector augmentors
- Hybrid tandem fans
- Remote augmented lift systems
- Mixed flow vector thrust systems

The ejector augmentor concept was also the focus of a joint U.S./Canadian research effort that included tests of a full-scale model of the E-7, a transonic configuration. An issue that surfaced in the E-7 program was the large, bulky size of the ejector systems. More research will be needed if the design is to be practical for future military aircraft.

Ames Research Center's V/STOL Systems Research Aircraft (VSRA), a highly modified prototype Harrier, recently began tests to characterize the exhaust plume of V/STOL aircraft with infrared cameras. The VSRA is also being used to evaluate advanced cockpit displays and integrated flight/propulsion controls. ➤

In March 1991, senior officials from NASA, the Department of Defense, the Air Force and industry—even the President's Science Advisor—appeared before Congress and testified with one voice: The National Aero-Space Plane (NASP) program is a high-priority national endeavor that is making excellent progress and has their full support.

The NASP program is geared toward production of a sleek flight research vehicle designated the X-30, which will make its first flight in the late 1990s. Its ultimate goal is to develop and demonstrate the technologies for single-stage-to-orbit flight; NASP will take off like an aircraft, accelerate into Earth orbit using supersonic ramjets (scramjets) as its primary propulsion, then return through the atmosphere for a runway landing.

The program is now in the middle of its technology development and verification phase. Researchers are acquiring data, defining vehicle systems and settling on engine and airframe designs. A Presidential decision to build and flight test the X-30 is slated for late 1993.

NASP nozzle tests at Lewis Research Center focused on operating characteristics from takeoff to about Mach 2. To reduce transonic drag, hydrogen fuel is burned in an external stream of air passing adjacent to the nozzle cowl section.

Overleaf: National Aero-Space Plane.

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DEVELOPING CRITICAL TECHNOLOGIES TO SUPPORT THE X-30 NATIONAL AERO-SPACE PLANE (NASP) AND FUTURE HYPERSONIC VEHICLES.

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THE NATIONAL CONTRACTOR TEAM

Because the goal of the NASP program is to build an unprecedented aerospace vehicle, the research and development effort requires unprecedented cooperation among government agencies, business organizations and academic institutions.

Early in 1990, five of the nation's leading aerospace companies—General Dynamics, McDonnell Douglas, Pratt & Whitney, Rockwell International and Rocketdyne, a division of Rockwell—took a "giant leap" forward in working together. They formed a NASP National Contractor Team to combine their technical expertise and their best ideas.

It was an innovative step. Instead of just one contractor coming up with new ideas for NASP technology, government and industry alike could capitalize on their synergism of ideas. Formation of the team also ensured that several companies would have the technical expertise to design and manufacture advanced propulsion systems, materials and structures derived from the NASP program.

Under the team agreement, Rockwell, McDonnell Douglas and General Dynamics are responsible for developing the X-30's airframe. Rocketdyne and Pratt & Whitney are addressing the NASP propulsion systems.

WANTED: TWIN TAILS, LIFTING BODY SHAPE

In October 1990, NASP reached one of its most significant milestones when a new, improved configuration was chosen for the vehicle. The twin-tailed, lifting body shape was distilled from the individual designs of the contractor team members.

The paired vertical tails will give the X-30 better stability and controllability during the atmospheric parts of its flight path. The vehicle's forebody will compress and force air into the scramjets at high speed, where oxygen from the air will be combined and burned with hydrogen carried on board. As the exhaust exits the scramjets, the X-30's afterbody will act as an expansion nozzle. Two pilots will fly the X-30 from a raised blister near the craft's flattened nose.

Some aspects of the NASP vehicle continue to evolve. The X-30 may incorporate elevons (combined elevators and ailerons) like those on the Space Shuttle orbiter, or the wings may be "all-moving" to provide pitch and roll control.

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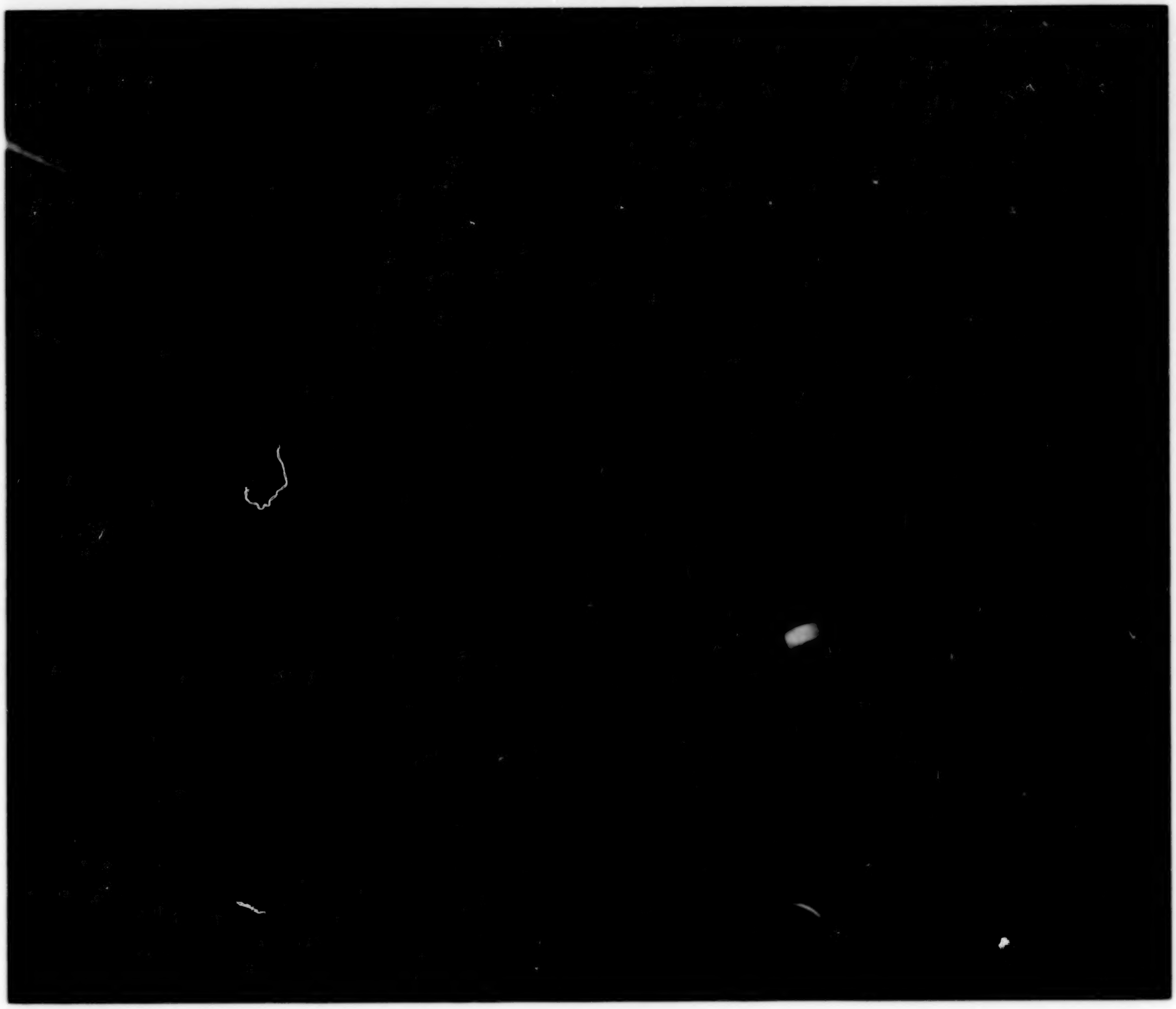

NASA engineer checks Test Technique Demonstrator (TTD) model in Langley Research Center's 14x20-foot subsonic wind tunnel. The fiberglass model is 9.5 feet long.

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NASP SYSTEMS INTEGRATION

The National Aero-Space Plane (NASP) Program is producing major advances in propulsion, materials, structures, aerodynamics and a host of other technical disciplines. But the success of the program depends on combining all of these technology developments into a "first-of-its-kind" aerospace plane (the X-30) that will take off horizontally and accelerate through the atmosphere, using airbreathing propulsion, to low Earth orbit. Langley Research Center's Larry Hunt discusses the formidable task of NASP technology integration and vehicle design. ►

There are a tremendous number of elements/variables involved in the synthesis of the aerospace plane. These variables are intricately networked and all are important. If the elements are integrated in a synergistic fashion, the design converges to a viable vehicle: there is a positive cascading effect. On the other hand, the design is just as sensitive in the other direction.

With NASP, the high degree of integration of the propulsion system with the airframe and the coupling between propulsion surfaces and aerodynamic surfaces make this a more highly integrated vehicle than has been attempted before. The X-15 was a high-Mach vehicle, but there was essentially no coupling between the aerodynamics and the propulsion; you lit the rocket, it ignited and accelerated.

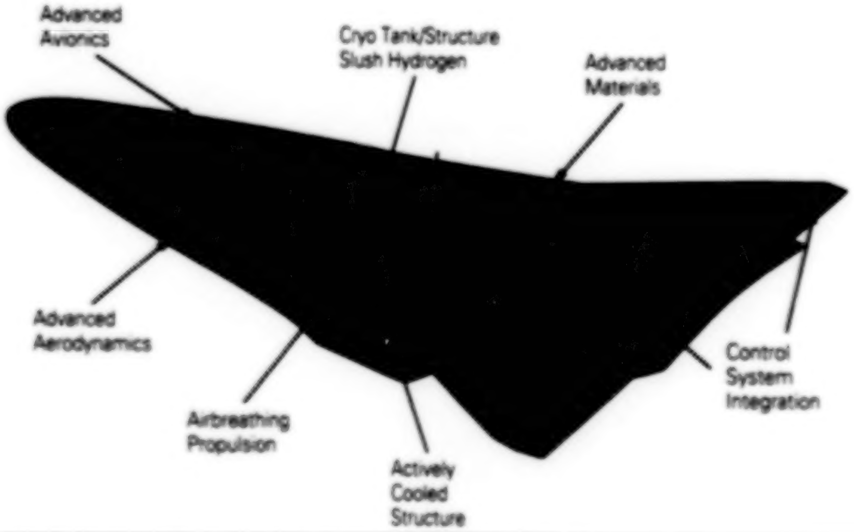
The X-30's forebody will precompress the air for delivery to the inlet/combustor and the afterbody will act as a nozzle to expand the exhaust, so the propulsion system is totally integrated from nose to tail on the undersurface of the vehicle. When the pilots change the power setting, they will change the forces in the nozzle and this in turn will require adjustments in aerodynamic controls for stable flight.

Another important coupling involves thermal management. Since the vehicle accelerates to low Earth orbit through an airbreathing corridor, the heat load during ascent is approximately three times that which occurs during reentry and descent. In order to manage this heat load, the cryogenic hydrogen fuel is used to actively cool the engines, a portion of the forebody inlet ramps and nozzle expansion surfaces and leading edges of the airframe. In this manner, the use of very high-temperature heavy materials is minimized. Also, the more heat absorbed by the fuel, the higher the fuel injector temperature—a significant factor in enhancing propulsion efficiency.

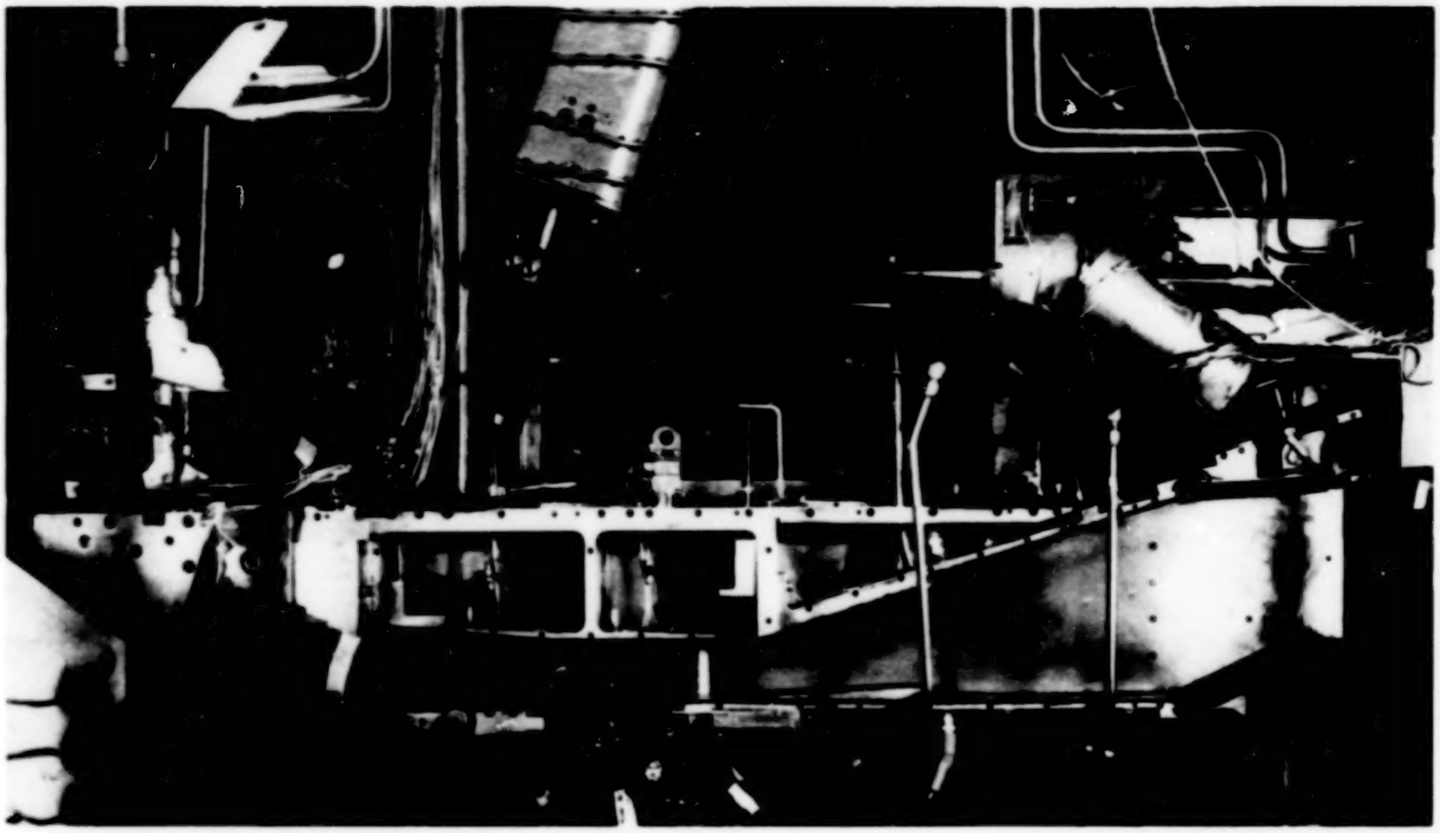
The aero-space plane is a highly sensitive machine and, thus, must be finely tuned for its orbital mission. However, it does have some "forgiving" characteristics. If, for example, the propulsion system does not attain the maximum efficiency predicted, the trajectory and the trajectory events can be re-optimized through the use of liquid oxygen (LOX) augmentation, in both the airbreathing scramjets and the rockets (when they are initiated at the top end of the trajectory) to increase the thrust-to-drag ratio of the vehicle and, thus, compensate for some scramjet propulsion efficiency losses.

This optimization will continue during the envelope expansion/flight test program. For instance, the scramjets cannot be tested in free-jet ground tests above Mach 8 nor in direct-connect combustor tests above Mach 10. Therefore, the airbreathing propulsion system design must rely on CFD (computer) predictions for the remainder of the trajectory to orbit. As the vehicle's flight test envelope is expanded beyond the ground-test matrix, the ratio of LOX to hydrogen on board will be flexible. The flight envelope expansion will substantiate the performance level attainable, and the LOX-to-hydrogen ratio can then be optimized based on actual performance.

NASP is an ambitious program. Today's fastest airbreathing airplane, the SR-71, cruises at about Mach 3; and NASP is attempting to accelerate to Mach 25. But, if the disciplines are integrated synergistically in the design of the vehicle, then a viable orbital vehicle should emerge that will provide routine access to low Earth orbit at substantially reduced cost. ►


Advanced Avionics
Cryo Tank/Structure Slush Hydrogen
Advanced Materials
Advanced Aerodynamics
Control System Integration
Airbreathing Propulsion
Actively Cooled Structure

Advanced technologies that will be integrated in the X-30.



Modified "government baseline" engine at Lewis Research Center. Model was used to obtain inlet and engine performance data with variable inlet contraction ratios and nozzle exit areas up to Mach 3.5.

NASA also has finished initial studies of crew escape options, including ejection seats and a separable nose section. A major requirement is to provide the crew with the maximum possible protection during the high-risk parts of the X-30's flight envelope.

MEETING THE TECHNOLOGY CHALLENGE

In the past two years, the X-30 has started to come off the drawing board and into reality. The national government/industry team has made impressive strides in developing the advanced technologies that will be integrated into the NASP vehicle.

➤ **AEROTHERMODYNAMICS**—
The aerodynamic data base continued to grow to meet the program's requirements. General Dynamics tested models over a speed range of Mach 4 to 14, complementing data previously obtained by McDonnell Douglas and Rockwell International. At Langley Research Center, NASA got valuable information on NASP-related stability and control, aerodynamic integration and propulsion with a series of powered Test Techniques Demonstrator (TTD) model tests.

➤ **PROPULSION**—
Lewis Research Center evaluated several engine inlet concepts to explore the interaction between engine modules. Scramjet fuel-injectors were the object of Mach 10 tests at the General Applied Science Laboratory and Mach 7 experiments at The Johns Hopkins University Applied Physics Laboratory.

Lewis researchers also ran tests of a complete "government baseline" engine design. The studies provided important insights into both performance and options for engine control systems. And Langley Research Center performed subscale scramjet investigations with contractor engine hardware in the Center's arc-heated scramjet test facility. Lewis' Plumbrook Facility began to produce large quantities (up to 500 gallons) of slush hydrogen, a mixture of solid and liquid hydrogen. Slush hydrogen will, in effect, give the X-30 more "bang for the buck"; it is denser than liquid hydrogen and requires smaller tanks for the same amount of propulsive capability. Tanks themselves can be lighter because slush hydrogen requires an internal pressure of only one pound per square inch. It is also a better coolant for the NASP structures and engines than liquid hydrogen.

ASSIGNMENT: X-30 TEST FLIGHT

Sometime in the late 1990s, the X-30 National Aero-Space Plane (NASP) will light up its engines and lift off the runway at Edwards Air Force Base in California. The sleek, black and gray vehicle won't be headed for orbit; in fact, the landing gear probably won't even be retracted. That first test hop will be just the start of a series of ever more ambitious experimental flights that will culminate in a try for single-stage-to-orbit after the turn of the century.

Though takeoff is several years in the future, NASA's Ames-Dryden Flight Research Facility at Edwards has performed many simulations of X-30 flight profiles since 1988. The research is being done in Ames-Dryden's Simulation Laboratory.

Early NASP test flights will focus on basics: proving that the X-30 flies as predicted in low-speed atmospheric flight and working out any technical problems that crop up in the vehicles's myriad electric, mechanical and propulsion systems. During this initial phase, the X-30 will be kept within the Edwards test range—at 20,000 square miles, still a huge area in which to fly!

Gradually, the X-30 will expand its speed and altitude envelope on a flight path that will far exceed in distance anything done in previous research aircraft programs.

The Mach 6.7 X-15 rocket plane of the 1960s, for example, used a "high range" stretching from mid-Nevada to Edwards in southern California. In one flight profile currently being studied by NASP program managers, the X-30 would leave Edwards and head southeast across the United States. It would cruise at speeds up to Mach 4 and altitudes far above normal military and commercial air traffic until it approaches NASA's Kennedy Space Center (KSC)—2500 miles from its home base.

If any problems developed, the plane would have enough energy to make an emergency touchdown at KSC's 15,000-foot Shuttle Landing Facility runway. If not at KSC, the X-30 would make a sweeping 180-degree turn, then accelerate to the speed planned for that particular run.

After gathering the needed data, the X-30 would cut off its scramjet engines somewhere over western Mississippi or eastern Texas and make a high-speed gliding return to the Edwards area. The low-speed propulsion system would be turned on at some point before touchdown to give the X-30 a "go-around" capability.

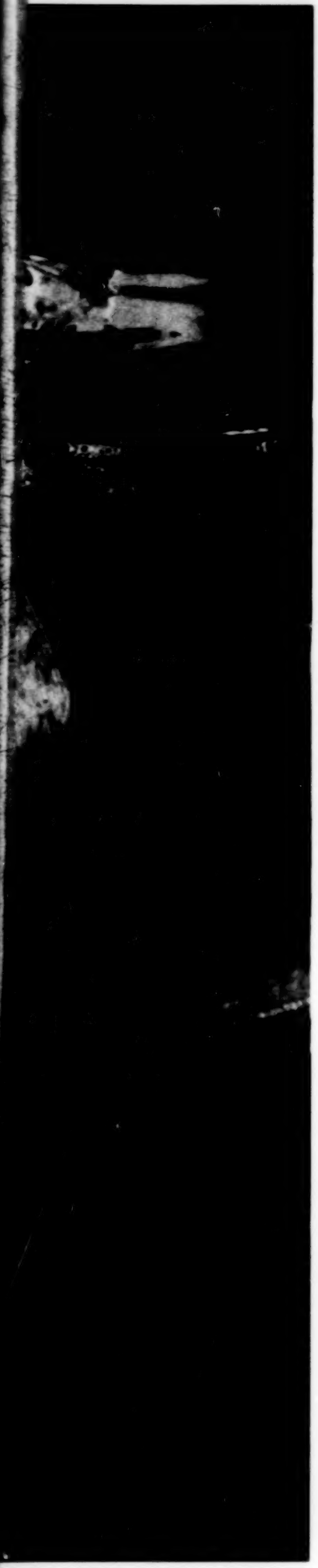
NASA and the Air Force haven't yet determined a final trajectory for flights to orbit. But one thing is certain: The X-30 will go where no "X-plane" has gone before. ➤

FLIGHT TEST POTENTIAL PROFILES

TRAJECTORY COMPARISONS

Altitude
(1000 ft.)
Mach Number

Potential ground tracks for X-30 flight tests (blue) encompass much more territory than those used in the X-15 program (magenta).



Cryogenic Propellant Tank Facility at Lewis' Plum Brook Facility will be used to study storage issues associated with slush hydrogen.

➤ MATERIALS AND STRUCTURES— The first large-scale structures representative of elements of the X-30 have been manufactured. McDonnell Douglas completed two series of tests on an eight-foot long, multi-lobed thermoplastic fuel tank installed in a fuselage-shell of titanium metal matrix composite. Also, large panels of silicone-fiber-reinforced titanium from Textron were assembled into a representative 4x8x8-foot NASP structure and sent to NASA's Ames-Dryden Flight Research Facility for thermal tests. General Dynamics and LTV Corporation completed an all carbon-carbon structure representing a 10x5-foot wing section of the X-30.

➤ COMPUTATIONAL FLUID DYNAMICS (CFD)—
As a result of test data validations, the NASP team now has increased confidence in aerothermal computer codes and has started to use CFD to design engine interior details. Researchers have also developed a combination of computer programs that can calculate nose-to-tail flow characteristics for the entire NASP vehicle.

Recent advances at Langley Research Center in boundary-layer transition prediction for hypersonic speeds have now been incorporated into contractor methods crucial to designs for surface heating and engine inflow.

GENERIC HYPERSONICS

NASA also is doing research to understand the fundamental physical processes of hypersonic flight and to promote new ideas applicable to hypersonic vehicles. The Generic Hypersonics program emphasizes research and technology development, primarily for airbreathing aero-space craft that use highly integrated airframe/propulsion concepts.

Unlike the NASP program, which is focused on a specific vehicle and mission, Generic Hypersonics stresses a broad range of configurations and technical issues. Key challenges exist in areas such as hypersonic boundary layers and high-speed transitions, mixing and combustion at supersonic speed and rarified flows at high altitudes.

An important part of the program is an effort to enhance general hypersonic capabilities through a variety of activities: ground-based research, flight experiments, investigations of the interaction of integrated components and development of super-accurate computational fluid dynamics algorithms. ➤

NASA strongly supports research to advance the technical disciplines important to aviation. The emphasis is on fundamental understanding of the physical phenomena involved in aerospace systems and on identifying and developing new ideas that may yield revolutionary advances for application to those systems.

By its nature, discipline research is continuous and long-range; it gives designers a technological foundation to draw on as they address the specific requirements of future aircraft. This fundamental technology base advances steadily through both computational and experimental research on the "leading edge." This base provides the knowledge needed to understand the key physics of structural, control and flow phenomena that make major breakthroughs in new concepts possible.

This work depends on the expertise of the researchers involved and on the experimental and computational facilities available to support the research.

➤

PIONEERING THE DEVELOPMENT OF INNOVATIVE CONCEPTS AND PROVIDING PHYSICAL UNDERSTANDING AND THEORETICAL, EXPERIMENTAL AND COMPUTATIONAL TOOLS REQUIRED FOR EFFICIENT DESIGN AND OPERATION OF ADVANCED AEROSPACE VEHICLES.

➤

UNDERSTANDING A PHENOMENON

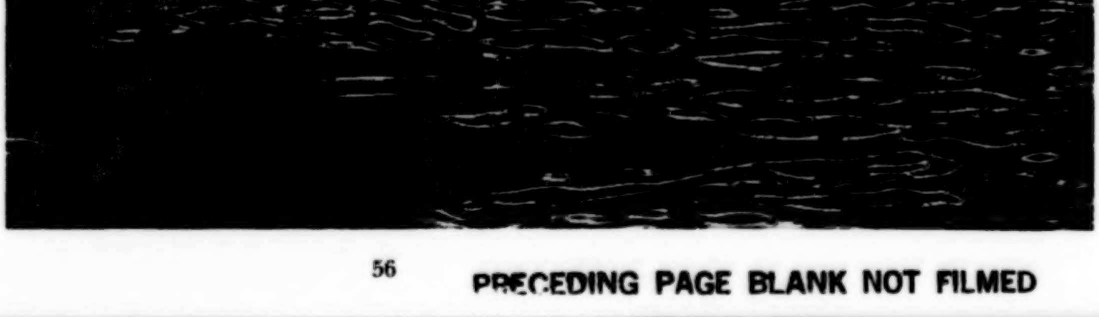
Boundary layer transition is a phenomenon much better understood today than it was just a few years ago. It is associated with the flow of air over an airplane in flight and the viscous effects that cause the air next to the aircraft's surface to flow at a lower velocity than the air in the "free stream" farther away.

This boundary layer has a very large effect on the level of drag and the corresponding engine thrust required to overcome it. Under certain conditions, the boundary layer is very uniform and smooth (laminar). In other situations, the layer transitions into an agitated state and becomes turbulent or unsteady and contains mini-tornados called vortices. Air friction drag on a plane is significantly higher with turbulent flow than it is for laminar flow, so understanding the boundary layer phenomenon and being able to model it and predict transition from laminar to turbulent can have a major impact on aircraft design and efficiency.

Scientists at NASA's Ames Research Center recently made the first direct numerical simulation of this transition to turbulence over a flat plate. Using a new "finite-difference" computational method, they were able to visualize detached shear layers of airflow and pairs of counterrotating vortices—results that agreed with the available experimental data.

The finite-difference method from this study has now been

Direct numerical simulation predicting transition from laminar to turbulent flow over a flat plate.



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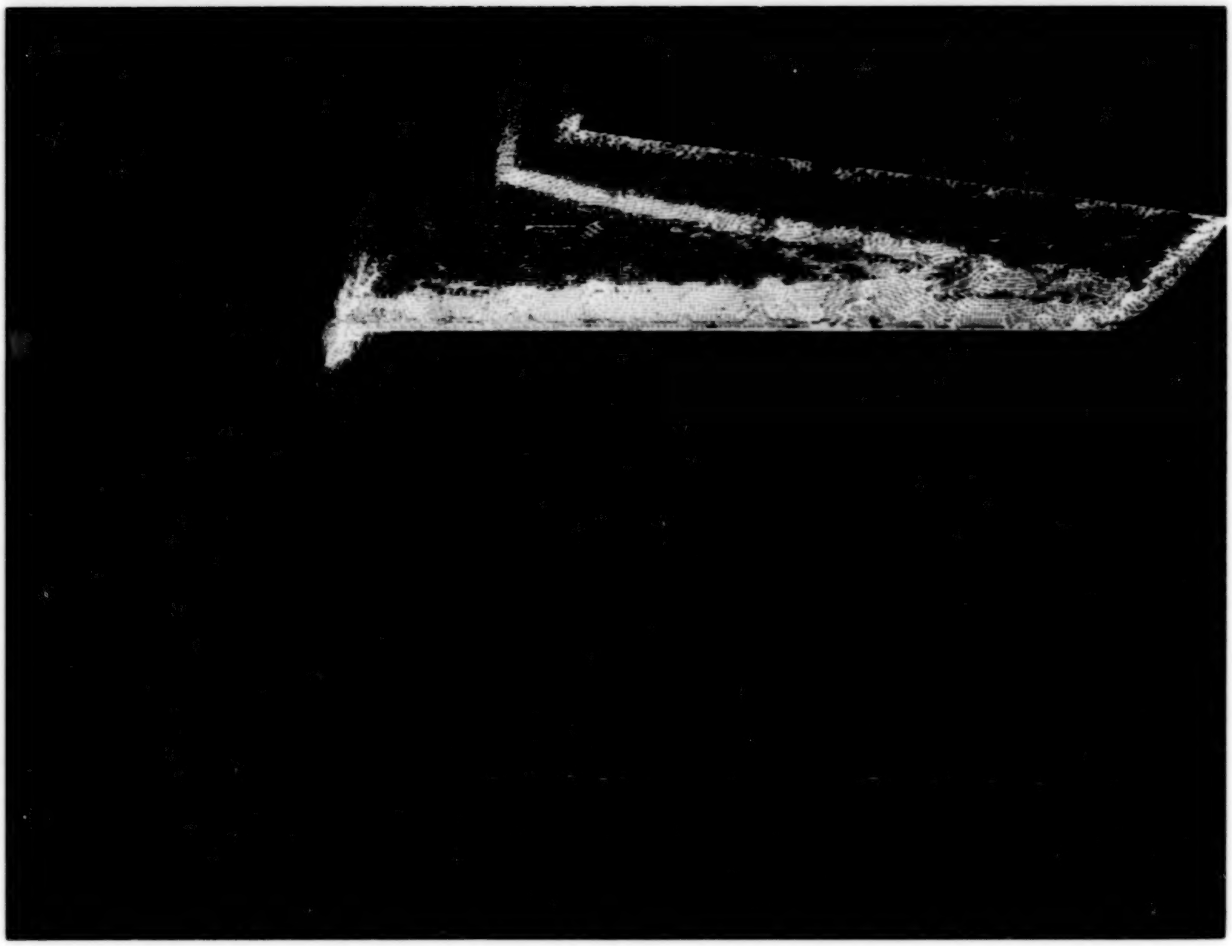

Triangular grid system produced prediction of the wing shock system about a wing at cruise conditions resulting in transonic flows. Mach contours are represented on wing surface by blue-green-yellow-red (low to high).

extended so that direct simulations of transitional and turbulent airflow over general shapes are possible. One of the first applications will be the creation of a new computer code to model compressible, turbulent and transitional flows over a turbine airfoil.

ADVANCED MATERIALS

Major leaps in materials technology have occurred as computational capabilities have allowed study of previously uninvestigated phenomena. Today, materials properties and processing behavior can be evaluated at the atomic and molecular level; this can lead to the development of materials with specific desired characteristics.

Researchers in polymers and metals have now formulated new combinations of elements to achieve higher service temperatures, increased toughness and improved corrosion resistance. Toughened polymeric plastics, when used in reinforced composite materials, improve the ability of a structure such as an airplane wing to withstand impacts from hail, runway stones and dropped tools. Unique combinations of electrical, mechanical and thermal properties, such as piezoelectrics and shape-memory materials, have also been created; uses for them in sensors and other applications are being developed.

NUMERICAL AERODYNAMIC SIMULATION

SINCE 1985, NASA'S NUMERICAL AERODYNAMIC SIMULATION (NAS) PROGRAM HAS PIONEERED ADVANCED AEROSPACE APPLICATIONS FOR SUPERCOMPUTERS. DAVE COOPER AT AMES RESEARCH CENTER, HOME OF THE NAS FACILITY, TALKS ABOUT THE PROGRAM'S ACHIEVEMENTS. ➤

To me, the Numerical Aerodynamic Simulation (NAS) program is one of the most successful that NASA has ever undertaken! It acts as a pathfinder to develop, integrate and test advanced computer systems and provides a leading edge computational capability to the U.S. aerospace community. We supply supercomputer services to more than 1500 users from NASA, the aerospace industry, the Department of Defense and university sites across the country.

I believe leadership in computational technologies will have a profound effect on the competitiveness of our aerospace industry in the 1990s. Computational simulations made possible by NAS will yield innovative solutions and designs that are not likely to be discovered by other means.

For example, research scientists using the NAS capability have developed computational fluid dynamics (CFD) codes that can predict the viscous flow field over entire aircraft, both civil transports and high-performance military airplanes. Minor modifications to candidate configurations can be easily accommodated, and the resulting impact on performance over a wide range of flight conditions can be quickly evaluated. Obviously, this significantly reduces design time and minimizes cost.

The list of NAS accomplishments and the testimonials from our users is quite impressive. Let me just mention a few.

We've done a numerical simulation of a wind tunnel test on an F-16A fighter to demonstrate that CFD can predict vehicle aerodynamics accurately at various angles-of-attack. The computed lift and drag coefficients and surface pressures agreed with the wind tunnel measurements to within 5 percent. Again, this capability reduces the overall requirements for wind tunnel and flight tests and shrinks the design time.

We have also performed a simulation of rotor/stator interactions in single stage turbines and simulations of unsteady flow in multistage turbomachines. These tests are helping researchers understand and define the pressure and temperature distributions in the turbines. The work has already led to the redesign of turbines to make them more efficient and will eventually lead to designs that increase the lifetime of the turbine parts.

A third example of NAS achievements is the progress being made to simulate the flow field through a ducted fan and the external flow over the engine nacelle and cowl. This work will assist designers of ultra-high-bypass ratio engines that substantially improve propulsion efficiency over existing powerplants.

Another important element of this work is the efficient integration and design of these large engines into the airframe and the resulting change in structural requirements.

During the past couple of years, the helicopter community has made tremendous strides in developing codes that accurately predict the helicopter/rotor blade airloads and performance as well as simulate the complicated flow that results from the fuselage, rotors and wake interactions. This work is currently demonstrating the applicability of CFD to this discipline and will eventually lead to rotary wing designs with improved performance and reduced noise and vibration.

As we move toward designing optimized vehicles that include the integrated effects of aerodynamics, controls, flexible structures and propulsion systems, we must develop multidisciplinary codes and apply them to realistic problems. The successful numerical coupling of the Navier-Stokes solutions with the structural equations to simulate aeroelasticity of a flexible wing is an example of this work. ➤

Predicted static pressure ratio for an Allison ducted propfan at Mach 0.75.

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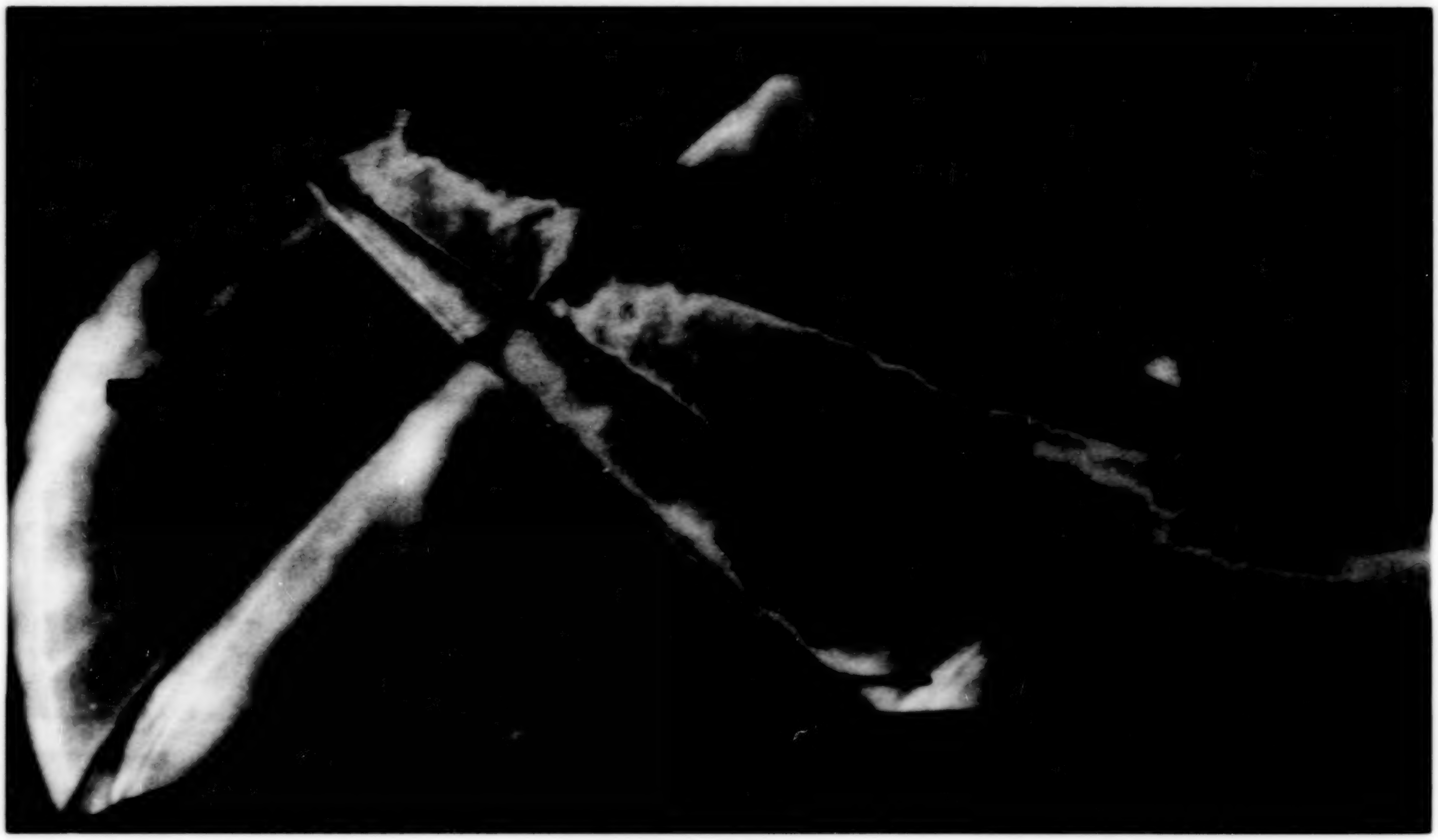


Luminescent paint glows under ultraviolet light in tests at Ames Research Center.

COMPUTATIONAL FLUID DYNAMICS

The design of future highly sophisticated aircraft is linked with the ability to compute accurately the flow of air around aerospace configurations. NASA is trying to make computational fluid dynamics (CFD) more effective in aircraft design by developing a basic understanding of such flows and correctly modeling phenomena such as turbulence and transition to turbulence for accurate predictions of aerodynamic drag.

The CFD process includes algorithms that translate equations of fluid motion into computer simulations, grid methods for modeling aerospace geometries and the volumes around them, and scientific visualization of computed results using color computer graphics workstations.

Recent developments by NASA researchers promise advances in treating geometric and physical complexities. For example, the flow about a wing was done using a triangular grid scheme that adapts well to the physical flow phenomena. The scheme improved accuracy in prediction of the wing shock system at cruise conditions resulting in transonic flows. Advanced grid schemes, when used interactively with sophisticated methods for visual display of the grids and final solutions, offer researchers several advantages:

- Full control for placement of discrete points
- Control of movement and views of the configuration
- Color enhancements of portions of the geometry
- Specific numerical data for the geometry and the solution.

THE "GRAND CHALLENGE" OF AEROSCIENCES

Computing and computer communications networks are transforming the world. They affect the way we do business, our educational activities—indeed, the way we live. Future societies with the most advanced computing capabilities will have a major competitive advantage in the world marketplace.

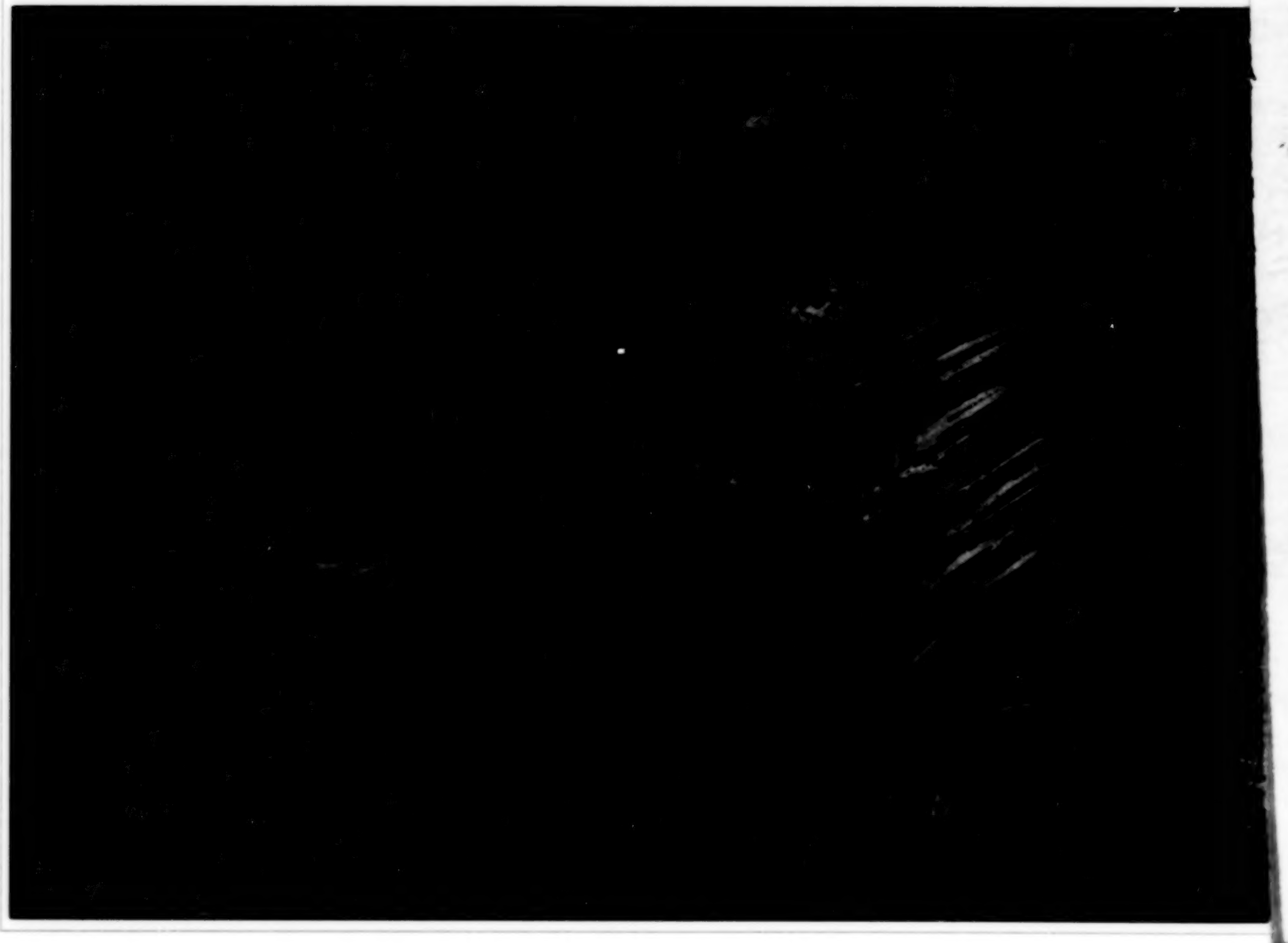
In 1991, the U.S. Government finalized details of a national program in High-Performance Computing and Communications (HPCC) to sustain and expand U.S. leadership in this area. HPCC is driven by the recognition that unprecedented computational power is needed to investigate and understand a wide range of scientific and engineering "grand challenges": problems whose solutions are critical to national needs. The program is a multi-agency endeavor that involves NASA, the Department of Energy, the National Science Foundation, the Defense Advanced Research Projects Agency (DARPA), the Department of Commerce, the National Institutes of Health and the Environmental Protection Agency.

NASA's part of HPCC is designed to accelerate the development and application of high-performance computing technologies to meet NASA's science and engineering requirements. The ability to do integrated, multidisciplinary numerical simulation and design of complete aerospace vehicle systems throughout the flight envelope is particularly important to the nation's continued preeminence in aeronautics.

The Computational Aerosciences (CAS) project is a major focus of NASA's HPCC efforts. Ames Research Center leads the CAS project with contributions from Langley and Lewis Research Centers. The program will work on technology for modeling critical system interactions in advanced aerospace vehicles that can't be done due to the limitations of today's supercomputers.

CAS will strive for progress in several areas. It will develop new algorithms and computational methods that can be effectively used with new "parallel-processing" computing systems. The project also will research new approaches to managing the data from those methods, from computational models and experiments, including highly complex complete aerosciences problems.

In more focused applications, CAS will research new multidisciplinary aeroelasticity and combustion models that will eventually be practical for engineering purposes. NASA's High-Speed Research Program, to develop technology for a next-generation supersonic transport, will be one of the prime



beneficiaries of this work.

NASA's participation in the High-Performance Computing and Communications Program will help the agency—and the nation—keep its current leadership in computational techniques, while broadly strengthening its capabilities for sustained high-performance computing research. ➤

Numerical simulation of exhaust streamlines from NASA's Vertical System Research Aircraft, a modified YAV-8B Harrier.

COMPUTATIONAL STRUCTURAL MECHANICS

Current aircraft structural design is typified by a top-down approach beginning with overall design and increasing in detail that results in the final engineering drawings. Employing evolving high-performance computers, computational structural mechanics (CSM) techniques offer a detailed design capability using advanced materials that can impact overall design. The result: lighter, better performing aircraft.

Recently, NASA research produced several milestones. A model for textile composites was used to predict static strength and fatigue life. This line of research will establish design requirements for new material forms. Adaptive analysis methods demonstrated new nonlinear solution techniques for predicting buckling and failure behavior in curved complex panels. Also, a combined experimental/analysis method to predict structural response of ceramic composites for engine structures was developed.

NEW EXPERIMENTAL TESTING TECHNIQUES

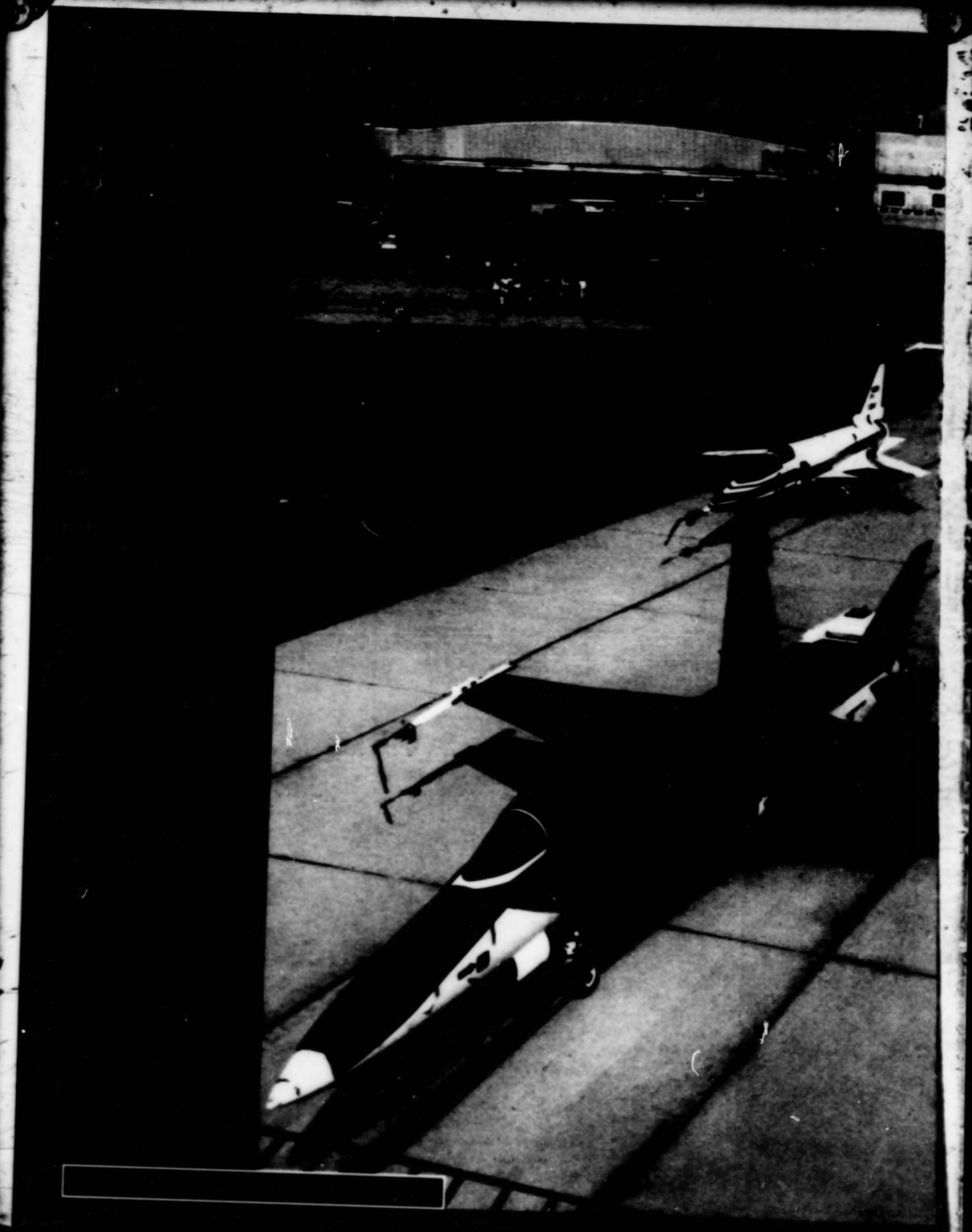
Computational solutions depend heavily on "real world" test results for validation. But experimental tests can be complicated, expensive and time consuming. They often require test facilities that simulate the flight environment and small-scale models that accurately represent the full-size article. Models must be extensively instrumented so that measurements can be made at many points on the surface for comparison with the computational solutions at the same points.

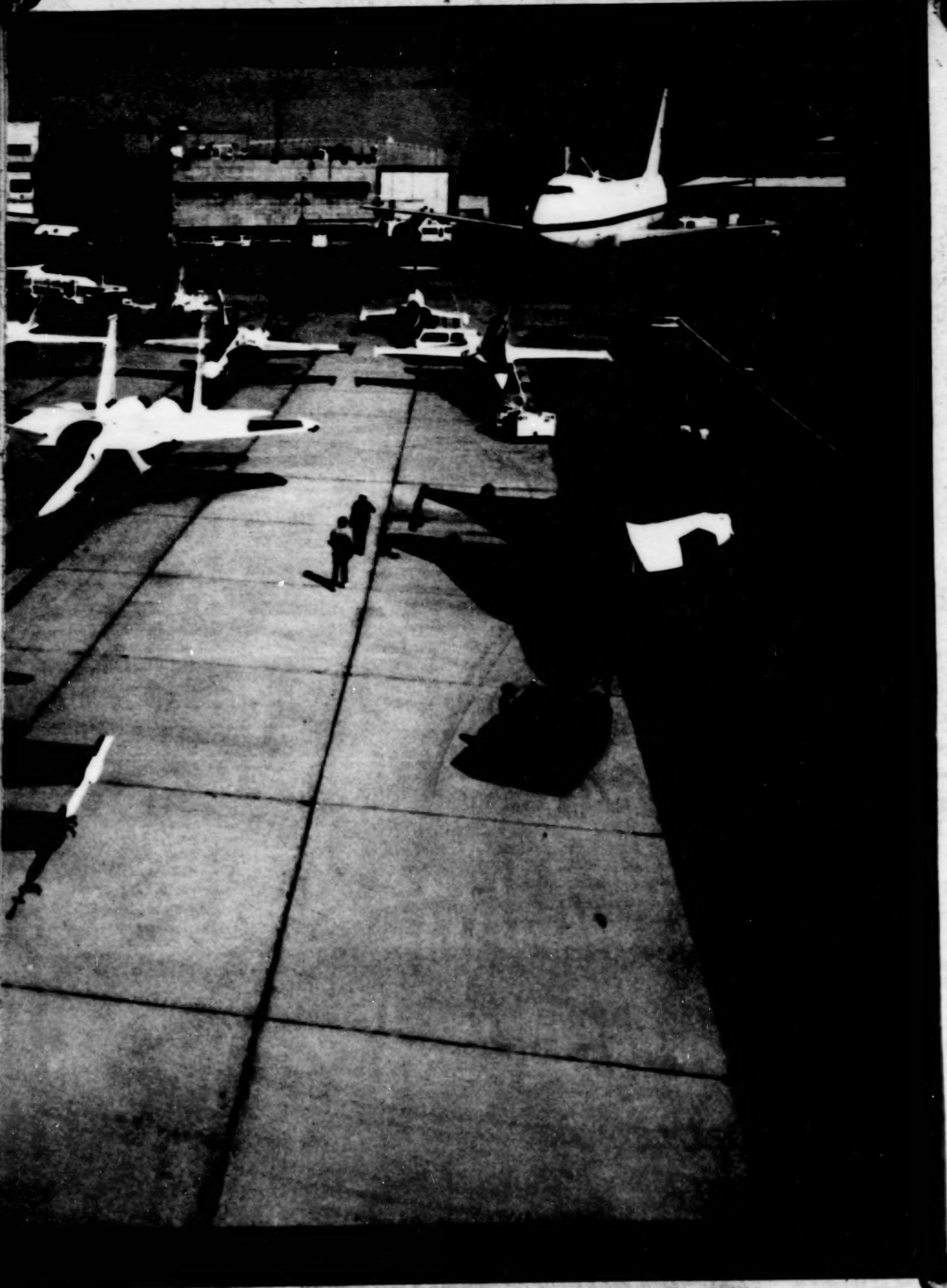
For example, aerodynamic tests of models in wind tunnels need many pressure taps placed at very precise locations on the model. The cost to manufacture such a model can run to more than $1 million for a model. The process of taking the measurements also is complicated and time consuming.

During the last two years, NASA has successfully tested a new paint that can measure surface pressure on aircraft during flight. The paint, developed by Ames Research Center and the University of Washington, becomes luminescent under ultraviolet light. The intensity of light radiated by the paint results from the aerodynamic pressure it receives. Researchers use videotapes or photographs taken in the ultraviolet to study the pressure patterns.

The paint's ability to give accurate pressure measurements was studied in wind tunnel tests at Ames in 1989. The method was validated during flight tests aboard an F-104 research aircraft at Ames-Dryden Flight Research Facility in 1991.

Aerospace experts are hailing the pressure-sensitive paint as revolutionary because it could lead to large areas of a test vehicle being studied at once. The light pink paint is quick and easy to apply and the entire test surface can be "mapped." Test models and flight vehicles don't have to be modified with the wires and tubing associated with conventional data collection systems. ➤





NATIONAL FACILITIES

▸

Developing, maintaining and operating critical national facilities for aeronautics research in support of industry, DoD and other NASA programs.

▸

The phrase "unique national asset" is often used to describe NASA's trio of research centers—Langley, Lewis and Ames—and the world's premier civilian flight test installation, the Ames-Dryden Flight Research Facility.

It's true that NASA's laboratories, wind tunnels and testing facilities rank among the world's best. The variety and scope of the programs already described in this report make it clear that the agency's partners in government and industry agree.

But the real value of NASA facilities to the nation cannot be measured solely in terms of their physical plant. Just as important are the first-rate scientists, engineers, technicians and managers who staff those installations. It's the combination of people and research capabilities that makes NASA's facilities so appealing to the aerospace community.

NASA also realizes that a physical plant must be maintained and periodically improved. The agency has in place an ambitious, integrated plan to upgrade its facilities and continue its ability to execute vital national aeronautics research programs.

Overleaf: Research planes at Ames-Dryden Flight Research Center.

NEW CAPABILITIES

In 1991, NASA brought two important new research facilities on line: the Ames-Dryden Integrated Test Facility (ITF) and Lewis' Powered Lift Facility.

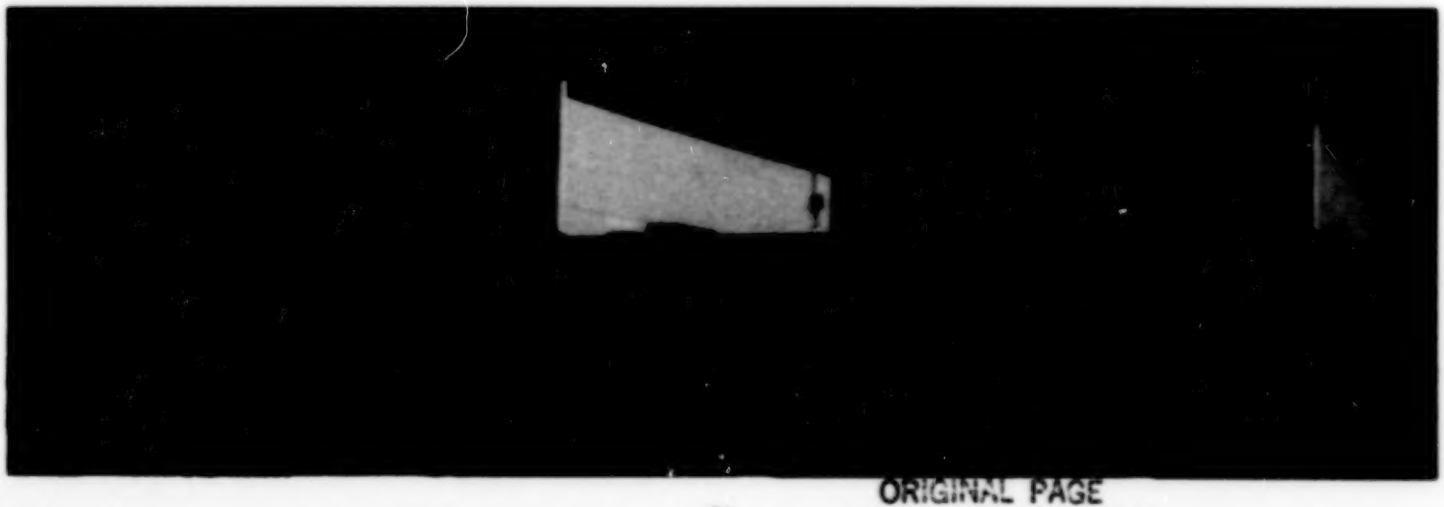
The Ames-Dryden Integrated Test Facility is essential for NASA's continued preeminence in aeronautical research. In the last decade, there has been a significant growth of electronic digital control for aircraft systems. Planes are being designed with integrated systems for, among other things, flight control, fire control, flutter suppression and flight management.

The ITF allows checkout of an aircraft's components and the interaction between components during overall operation of its integrated systems. The facility has aircraft test bays that can accommodate up to six aircraft. It also incorporates laboratories, office space and associated work space.

The Powered Lift Facility makes it possible for researchers to investigate full-scale Short Take-Off/Vertical Landing (STOVL) propulsion systems in prototype form. Advanced experimental test techniques can gather large-scale propulsion data on candidate STOVL concepts and can help assess their technical readiness. The facility is also being used to support the High-Speed Research Program.

The facility features a multi-axis force measuring system; roll, pitch and yaw moments can also be determined. The test rig supports models weighing up to 40,000 pounds and can supply compressed air to test articles at 400 pounds per second.

The Integrated Test Facility is on-line at Ames-Dryden Flight Research Facility.

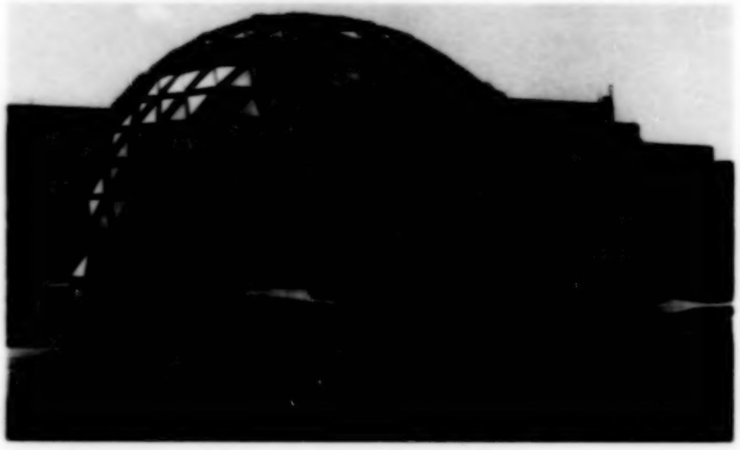


REVITALIZING NASA'S WIND TUNNELS

In 1989 NASA started a wide-ranging program to refurbish many of its major wind tunnels, some of which are 30-50 years old.

The program resulted from a 1987 study by a subcommittee of the Aeronautics and Space Engineering Board of the National Research Council. The study suggested that some of NASA's wind tunnels could be made more productive and reliable. One driver is competition: Most European tunnels are only 10-20 years old and are able to generate large quantities of high-quality data.

NASA's five-year Wind Tunnel Revitalization Program is modernizing the facilities and associated instrumentation in 15 tunnels at the Ames, Langley and Lewis Research Centers. About 70 percent of the $300 million required to complete the program will go directly to improvements in the wind tunnels. Upgrades to related support facilities will use about 20 percent and the remaining 10 percent will be devoted to updating data acquisition systems and other equipment.



Lewis Research Center's Powered Lift Facility features a multi-axis force-measuring system with a capacity of 30,000 lbs. axial force, 20,000 lbs. vertical force and 3000 lbs. lateral force.

When the Wind Tunnel Revitalization program is complete, NASA's aeronautical facilities will maintain their position as the world's premier research and development capability.

AN EXPANDED ROLE FOR AMES-DRYDEN

Starting from a modest group of five engineers in 1946, the Ames-Dryden Flight Research Facility has grown to a complex with more than 900 NASA civil servants and contractor personnel. Its location in the California high desert among several dry lake beds used as runways makes the base ideal for aerospace flight research. Moreover, Ames-Dryden includes laboratories to ground test aircraft structural components and avionics systems, as well as facilities to visualize flow-patterns over models and to process flight research data. This combination of location and capabilities gives Ames-Dryden an unmatched ability to conduct advanced flight research programs.

NASA wants to ensure that the nation receives the full benefit of Ames-Dryden's unique facilities. The agency is developing a forward-looking plan that will continue Ames-Dryden as America's flight research center, participating in all future U.S. experimental aircraft programs.

Ames-Dryden will help guarantee the success of tomorrow's research efforts such as the X-30 National Aero-Space Plane Program and other projects in flight stability, control and propulsion systems and technology for super-maneuverable aircraft. ►

The 12-foot Pressure Tunnel at Ames Research Center is in the process of renovation as part of NASA's Wind Tunnel Revitalization program.

AERONAUTICS ORGANIZATION

NASA's aeronautics research and technology program is directed by the Associate Administrator for the Office of Aeronautics and Space Technology (OAST). OAST is responsible for planning, advocating, directing, executing and evaluating projects and research activities concerned with aeronautics and space technology and for institutional management of the Ames, Langley and Lewis Research Centers and Ames-Dryden Flight Research Facility.

Within OAST, the Director for Aeronautics has overall responsibility for strategy, planning, advocacy, direction, execution and evaluation of aeronautics programs. The Director for Aeronautics also is a primary OAST liaison for aeronautics with Congress, advisory committees, industry, universities and government agencies. He ensures that the Aeronautics Directorate works closely with the other OAST Directorates; for example, there is continuing interaction with the Director for Space Technology on research activities that apply to both aeronautics and space and with the Director for Institutions on institutional planning, budgeting and advocacy of facilities at NASA's Research Centers.

The Aeronautics Directorate also establishes discipline program plans and objectives and determines facility requirements consistent with program strategy. The Research Centers implement and manage the aeronautics programs and participate jointly with OAST in developing strategic plans and establishing future research and facility requirements.

The Director for Aeronautics is supported by a Deputy Director and by four Division Directors for High-Speed Research, Subsonic Transportation, High-Performance Aircraft and Flight Projects, and Aeronautics Research. The Deputy Director, in addition to supporting the overall direction of the aeronautics program, focuses specific attention on broad strategy and policy issues. The respective Division Directors define research and technology needs, ensure the proper balance of vehicle-related and fundamental research and develop long-range plans within their areas. NASA's Aeronautics program encourages cooperative academic involvement in the agency's research activities, particularly in basic research.

The cone fairing in NASA-Langley's 16-foot Transonic Wind Tunnel helps to reduce disturbances in air flow around corners.

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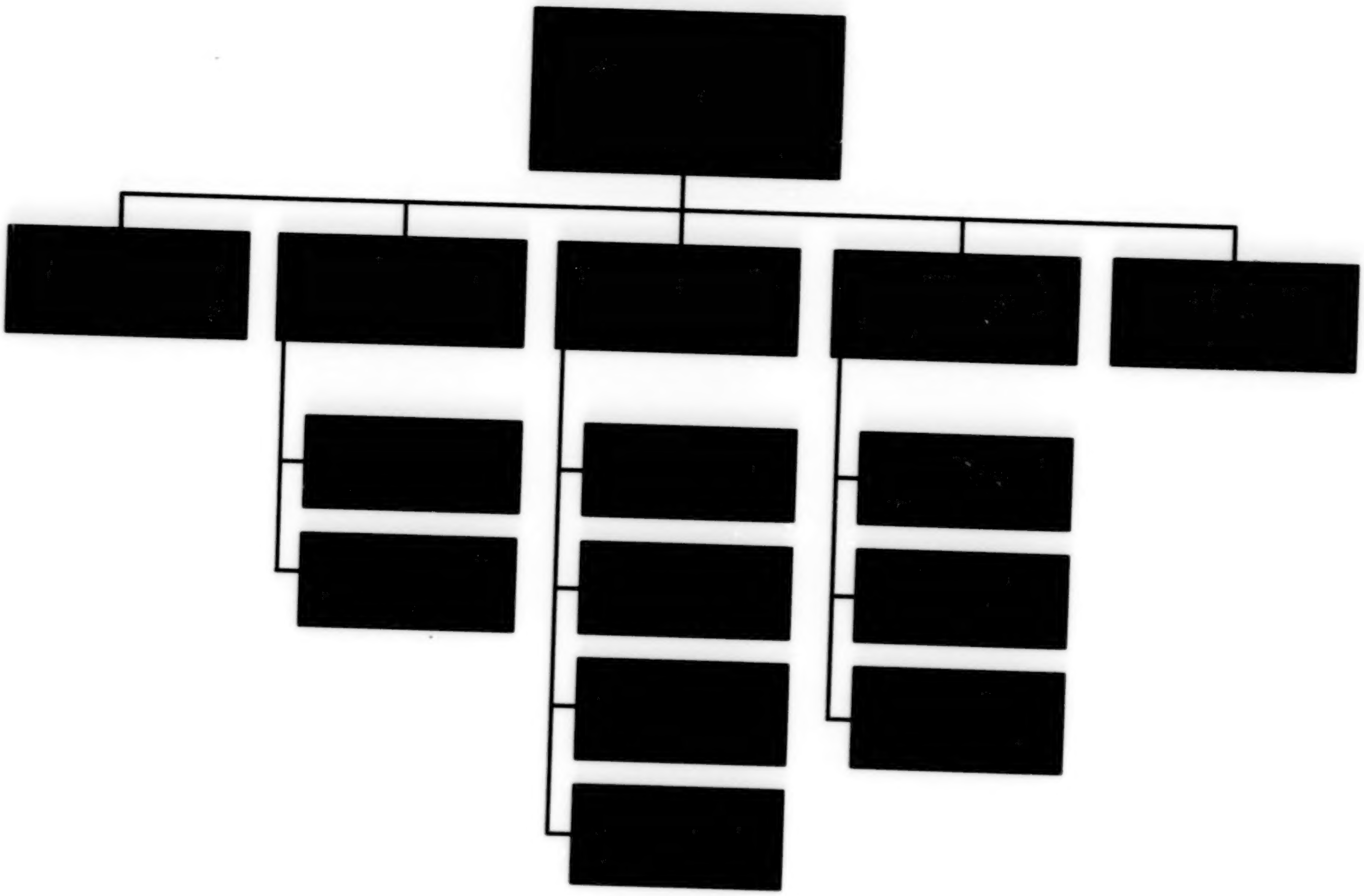
NASA ORGANIZATION



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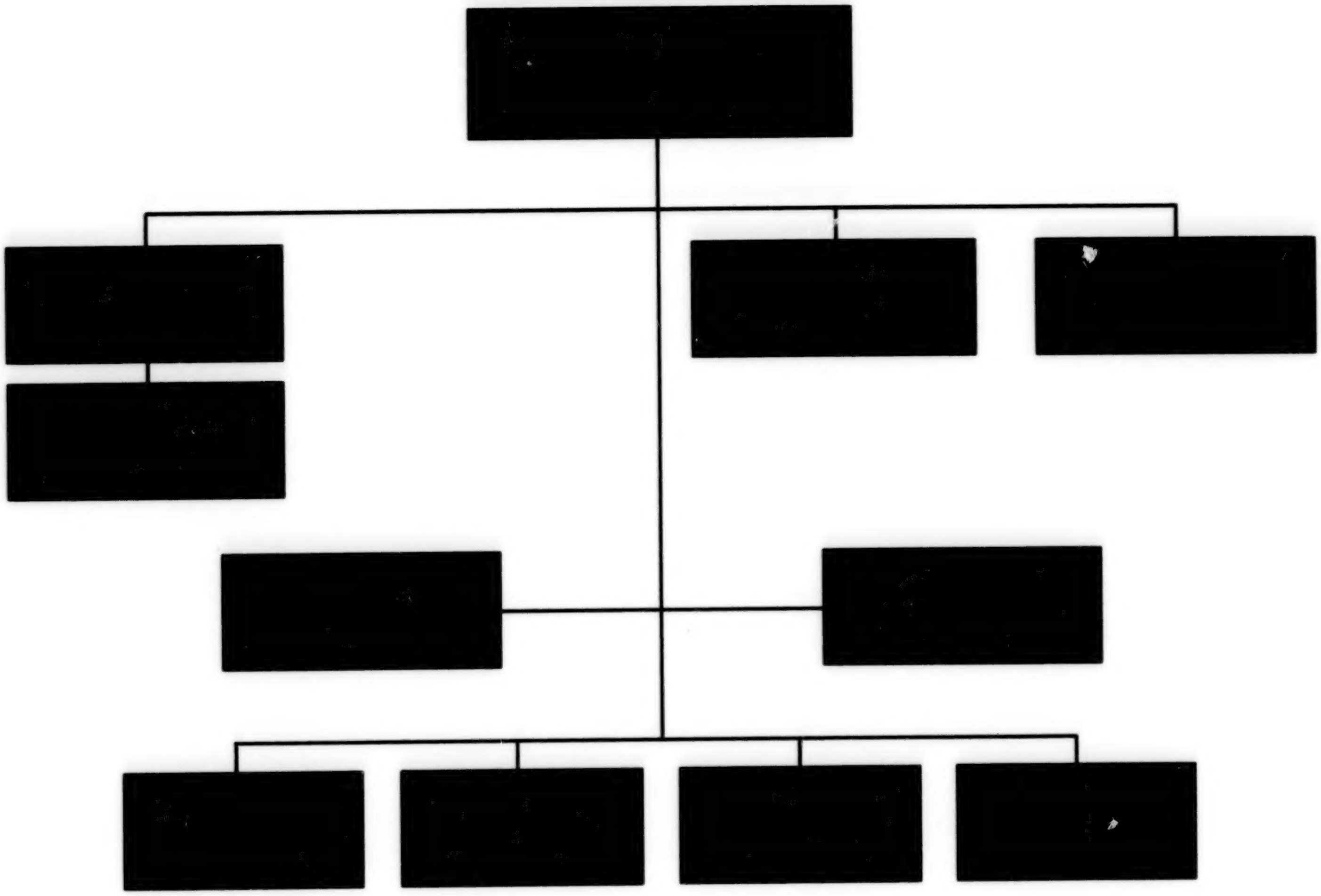
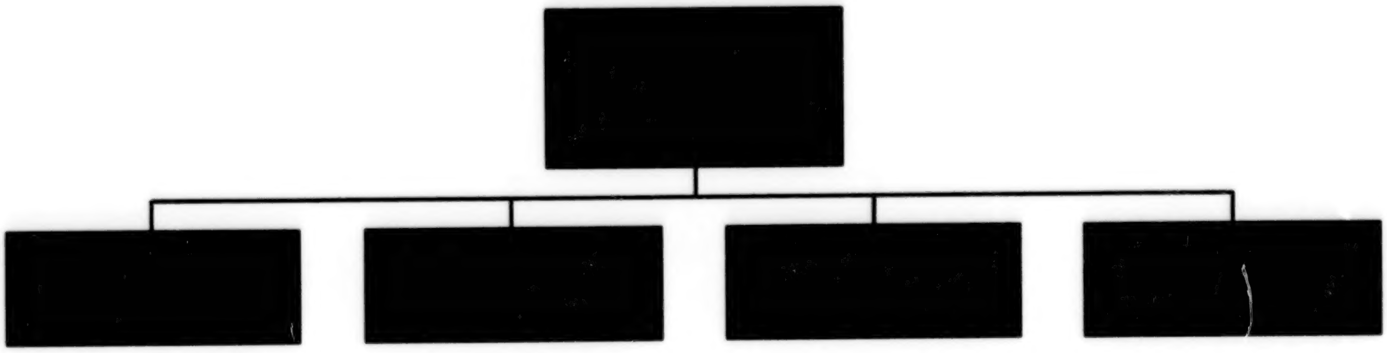
OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY



AERONAUTICS DIRECTORATE



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NASA RESEARCH CENTERS

Of the thirteen installations that comprise the business end of the National Aeronautics and Space Administration, Langley Research Center in Virginia, Lewis Research Center in Ohio, and Ames Research Center and its Ames-Dryden Flight Research Facility in California are the primary installations conducting NASA's aeronautical research and technology programs.

Each center, unique in its facilities and research staff, is a resource that brings to NASA the capabilities which have allowed the agency to maintain its worldwide leadership in aeronautics and space research and technology development.

But NASA does not work in a vacuum; each center conducts its research in close coordination with other agencies through cooperative agreements, with universities through NASA's many grant programs and with industry in cooperative research projects. One of NASA's aeronautics thrusts, the development of technology for hypersonic flight (foundation for the future National Aero-Space Plane), is an example of NASA/DoD/industry/university interdisciplinary cooperative efforts.

The chart presents each Center's responsibilities in carrying out NASA's strategic thrusts. The map shows the location of each research center and lists its Center Director and key aeronautical program mangers. ➤

AERONAUTICS

Strategic Thrust and Objective Responsibilities

	Ames	Langley	Lewis
Subsonic Aircraft/National Airspace			
Aerodynamic Efficiency	▨	■	□
Flight Management Concepts	■	■	□
Cockpit/ATC Integration	■	■	□
Composite Materials	□	■	□
Aircraft Safety	■	■	■
Noise Reduction	□	■	■
Tiltrotor Technology	■	▨	▨
High-Speed Air Transportation			
Atmospherics/Emission Reduction	▨	▨	■
Noise Reduction	□	▨	■
Sonic Boom	▨	■	□
Enabling Propulsion Materials	□	□	■
Airframe	▨	■	□
Propulsion	□	□	■
Cockpit	▨	■	□
High-Performance Military Aircraft			
Maneuverability & Agility	■	■	□
Powered Lift	■	□	■
Integrated Controls	■	□	■
Rotorcraft Agility	■	▨	□
Hypersonic/Transatmospheric Vehicles			
Aerothermodynamics	■	■	□
Materials & Structures	□	■	□
Propulsion	□	■	■
Critical Disciplines			
Aerodynamics	■	■	□
Propulsion	□	□	■
Materials & Structures	□	■	■
Human Factors	■	■	□
High-Performance Computing	■	■	■
National Facilities			
Major Wind Tunnels	■	■	■
Supercomputing	■	□	□
Flight Simulation	■	■	□
Flight Research	■	■	■

■ Major Capability/Role
▨ Supporting Capability/Role
□ NA

AMES
Research Center
Moffett Field, CA
D.L. Compton
V.L. Peterson
F.R. Bailey
C.T. Snyder

AMES/DRYDEN
Flight Research Facility
Edwards, CA
K.J. Szalai

LEWIS
Research Center
Cleveland, OH
L.J. Ross
J.S. Fordyce
N.T. Saunders
S.J. Grisaffe

LANGLEY
Research Center
Hampton, VA
P.F. Holloway
H.L. Beach
R.V. Harris, Jr.
J.F. Creedon
C.P. Blankenship

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AMES RESEARCH CENTER
Moffett Field, California

As one of NASA's premier facilities, Ames Research Center uses its unique complex of advanced supercomputers and wind tunnels to conduct pioneering aeronautical research. Ames is world-renowned for its research in computer science and applications, computational fluid dynamics (CFD), aerodynamics, flight simulation and research, hypersonic aircraft, rotorcraft and powered-lift technology and aeronautics and space human factors.

Current aeronautical research being conducted at Ames includes:

- Cockpit display/pilot fatigue and crew awareness and control
- Human-centered air traffic control aids
- Advanced fundamental understanding of aerothermodynamics processes and development of predicted capabilities for analysis and design optimization of advanced aerospace vehicles
- Computational structural mechanics
- CFD/80x120-foot tunnel work on high-alpha research
- Aerodynamic and acoustic prediction for rotorcraft and improved panel and helmet-mounted displays in pilot interface for civil and military rotorcraft
- Navigational accuracy and associated operational procedures
- Advanced automation tools to aid effective air traffic control of terminal area traffic

The Numerical Aerodynamic Simulation (NAS) Facility and the National Full-Scale Aerodynamics Complex (NFAC) are two of the largest and most impressive facilities at Ames. The unique NAS supercomputer system is the world's most advanced, capable of over one-billion computations per second.

The NFAC houses the world's largest wind tunnel providing the capability to conduct ground-based testing of full-scale and large-scale aircraft and their components. An additional 30 wind tunnels–some designed for speeds up to 34,000 mph–offer capabilities from low subsonic to hypersonic. The Vertical Motion Simulator and other flight simulators give NASA the ability to perform flight tests in a laboratory setting. ➤

AMES-DRYDEN FLIGHT RESEARCH FACILITY
Edwards, California

Located in the high desert country of California, Dryden Flight Research Facility is NASA's premier installation for aeronautical flight research, complementing the ground test capabilities of Ames and the other centers. Its location on Rogers Dry Lake, a natural playa, is ideal for aviation research and test operations and for Space Shuttle landings.

Dryden has been associated with many significant milestones in aeronautical research, from the X-1 supersonic research flights to the forward swept wing X-29 and the Space Shuttle. Facility researchers are making preparations for the flight test program of the X-30 National Aero-Space Plane (NASP) in the late 1990s.

Current aeronautical research being conducted at Dryden includes:

- Flight techniques and instrumentation on NASA research vehicles
- High angle-of-attack characteristics of the forward-swept-wing design with the #2 X-29
- Airflow, behavior of flight control surfaces and engine performance at high angles-of-attack with the F/A-18 HARV fitted with the thrust vectoring control system
- Integrated digital electronic flight and engine control systems for improved fuel savings and engine performance
- Laminar flow research at supersonic speeds with the F-16XL
- Design methodologies for integrated flight and propulsion controls for aircraft; correlation of research quality aerodynamic propulsion and control systems data base to develop design criteria for advanced aircraft

The X-30 is expected to be tested at Dryden in the late 1990s. The facility's Thermostructures Research Facility is carrying out early structures research on components that may be used to build the X-30. ➤

LANGLEY RESEARCH CENTER
Hampton, Virginia

For almost 75 years, Langley Research Center has been a leader in aeronautical research. The Center is currently known for its work in aerothermodynamics, computational fluid dynamics, aerodynamics and aeroelasticity, robotics and air-breathing propulsion systems for the NASP program. Langley is also one of NASA's key facilities for the development of aircraft flight control systems, visual displays and data networks. In addition, the Center does materials and structures research focusing on structural analysis methods and research in airframe metallic and composite materials.

Current aeronautical research being conducted at Langley includes:

- Advanced composites structures and materials for use in future primary aircraft structures
- Noise prediction and suppression technology for high-speed civil transports
- Airborne detection and avoidance of wind shear and heavy rain
- High-performance composites and light-weight metallic materials for use in advanced airframe structural applications
- Advanced controls displays and decision-making aids to increase cockpit efficiency and enhance capacity of national airspace system

To support its research, Langley has 40 wind tunnels that operate at speeds up to Mach 20, structures and materials laboratories, flight simulator facilities and an advanced scientific computer facility that includes the Cray-2 supercomputer.

The newest research facility for developing and testing high-performance aircraft is the National Transonic Facility. This wind tunnel uses cryogenic nitrogen instead of air to provide more realistic flight simulation in testing aircraft that fly at transonic speeds. ➤

LEWIS RESEARCH CENTER
Cleveland, Ohio

The Lewis Research Center is NASA's leader for aircraft propulsion, spacecraft propulsion, space power and materials technology research. NASA's research on aircraft icing and ice protection systems is performed in the Icing Research Tunnel, one of the world's busiest. As a leader in aerospace propulsion systems, Lewis is developing subsonic, supersonic and hypersonic technology.

Experimental research in materials, structures, and fluid dynamics is aimed at propulsion systems for use on future high-speed transports capable of transoceanic and transatmospheric flight. Unique components for these systems are being researched.

Current aeronautical research being conducted at Lewis includes:

- Advanced turboprop systems to provide aerodynamic acoustic and structural technology
- Small turbine engine technology to enhance U.S. manufacturers in the future marketplace
- High-temperature composite materials for applications to future propulsion systems
- Advanced concepts in propulsion emissions and noise reduction for future supersonic transports
- Advanced materials and processing technologies for high-temperature materials

Plum Brook, a field station of the Lewis Research Center, provides unique aerospace test facilities and large clear zone areas for hazardous tests with liquid hydrogen, oxygen and nuclear materials.

To support its research, Lewis' facilities include two supersonic wind tunnels able to test full-sized systems, the Icing Research Tunnel, the Powered Lift Facility, the Microgravity Materials Science Laboratory, a 420-foot zero gravity drop tower, an advanced supercomputer system and the nation's most modern rocket engine test facility. ➤

UNIVERSITY PROGRAMS

NASA's Aeronautics Program encourages cooperative academic involvement in the agency's research activities, particularly in basic research.

The NASA Aeronautics Program invests approximately 10 percent of its research and development resources in the nation's universities to conduct long-range, high-risk research; develop innovative, creative approaches to advancing basic technology; and enhance existing university technological curriculum. In 1990, nearly 150 institutions participated in over 650 projects involving a range of research topics from undergraduate engineering design studies through research in advanced materials, air traffic control technology and next-generation commercial transport aircraft conducted at the post-doctorate level.

The majority of these projects are in the form of Basic Research Grants, which are used by the universities to extend mainstream aeronautical basic research. Additional support is provided by the NASA Research Centers through the Fund for Independent Research, which stimulates innovative, high-risk research conducted at universities.

Although featuring only a portion of NASA's supportive resources, the following descriptions illustrate the breadth and extent of the agency's University Programs.

Research Institutes are located at the NASA Research Centers and are operated by a nonprofit consortium of major colleges and universities. The Institutes conduct unclassified basic research in applied mathematics, numerical analysis and computer science to strengthen specific capabilities in science and engineering.

Research is conducted primarily by visiting university and industry scientists and by consultants. With temporary resident appointments, visiting scientists have the opportunity to use the unique facilities of the centers while working with NASA personnel on specific research.

Research Center	Institute
Ames Research Center	Research Institute for Advanced Computer Science
Langley Research Center	Institute for Computer Applications in Science and Engineering
Lewis Research Center	Institute for Computational Mechanics in Propulsion

Centers of Excellence have been established at specific universities to develop unique expertise and to accelerate progress in new and emerging fields. A "critical mass" of key faculty at the universities is established to conduct research, train students and foster interdisciplinary interactions among the universities, the NASA Research Centers, the Department of Defense and industry.

Discipline	University
Ceramics	Pennsylvania State University
Computer Science	University of Illinois
Computer Science	Stanford University
Material Science	Virginia Polytechnic Institute and State University
High-Temperature Materials	Pennsylvania State University
Innovative Material Processing Science	University of Virginia

Joint Institutes established by the Research Centers promote an active NASA/university interchange in innovative research areas. The goal: to meet the nation's ever increasing needs in the advancement of science, engineering and technology and to prepare qualified students for careers in research, development, design and teaching.

Research Center	Joint Institute
Ames Research Center	Joint Institute for Aeronautics and Acoustics
Langley Research Center	Joint Institute for Advancement of Flight Science
Lewis Research Center	Ohio Aerospace Institute

The education and research opportunities offered in the program combine the academic resources of universities with those of NASA Centers. Students can become involved in projects that excite their interest and permit them to associate with university faculty and experts from NASA Centers.

The **University Advanced Design Program** is a unique program focused on enhancing the Aeronautics Design Curriculum for undergraduate students. Initiated in 1986, this Aeronautics Program brings together students and faculty with NASA engineers to provide a forum for the exchange of innovative design techniques. Students apply lessons learned to design projects during a senior year design course. These design projects are selected by the students in consultation with their NASA counselor and reflect alternate approaches to current NASA R&D areas of interest. The design projects are presented at an annual conference for review by student peers, faculty and NASA and industry representatives. Design projects vary from advanced computers to high-altitude aircraft and from combat aircraft to supersonic and hypersonic vehicles. The 1991 conference saw the initiation of a special session in which NASA researchers gave a special presentation on current efforts in multidisciplinary design methods.

Ten competitively selected universities participated in the program:

- Auburn University
- California Polytechnic State University, San Luis Obispo
- California State Polytechnic University, Pomona
- California State University, Northridge
- Case Western Reserve University
- University of Kansas
- University of Notre Dame
- Ohio State University
- Purdue University
- Worcester Polytechnic Institute

NASA has established **Training Grants in Hypersonics** with six universities, because programs such as the National Aero-Space Plane (NASP) are increasing our interest in hypersonic flight. These grants will stimulate and support the development of graduate level programs in hypersonic research.

The training portion of these programs will support developing graduate level curriculum, analytical/experimental course work and appropriate text material specifically focused toward the study of hypersonic viscous flow phenomena. The research portion will support fundamental research in hypersonics relevant to aircraft and missiles that fly from Mach 5 to 15. Participating universities are:

- Stanford University
- State University of New York
- University of Texas at Austin
- Ohio State University
- University of Southern California
- North Carolina State University

The **Graduate Program in Aeronautics** sponsors graduate training and research relevant and acceptable to both NASA and universities in the field of aeronautics and encourages a greater number of newly graduating engineers to pursue graduate training.

A significant portion of the training and research is student research conducted under the guidance and support of faculty and staff at a NASA Research Center. The long-term goal is to provide a cadre of research-trained graduate engineers who will continue U.S. leadership in aerospace design and construction.

The **NASA/National Research Council Resident Research Associateship Program** provides opportunities for post-doctoral and senior post-doctoral scientists and engineers to gain research experience in problems that are compatible with the research interests of the NASA Research Centers. Associateships are awarded for one year, but recipients may be considered for a second year. This program is administered by the National Research Council of the National Academy of Sciences.

The **American Society for Engineering Education Summer Faculty Fellowship Program** provides an opportunity for university faculty to do research at NASA's Research Centers during the summer. The program adds to the knowledge of the science faculty, stimulates the exchange of ideas between NASA and university personnel, enriches the research and training activities of the participants' institutions and contributes to NASA's research objectives.

Appointed Fellows spend 10 weeks in cooperative research and study programs. The study program uses lectures and seminars by distinguished scientists and engineers from NASA, universities and industry.

Each year, **NASA's Graduate Student Research Program** provides an opportunity for approximately 40 graduate students in aerospace science and technology to conduct their thesis research at a NASA Research Center. The Program is designed to raise the number of highly trained aerospace scientists and engineers who can meet the continuing needs of the national aerospace effort.

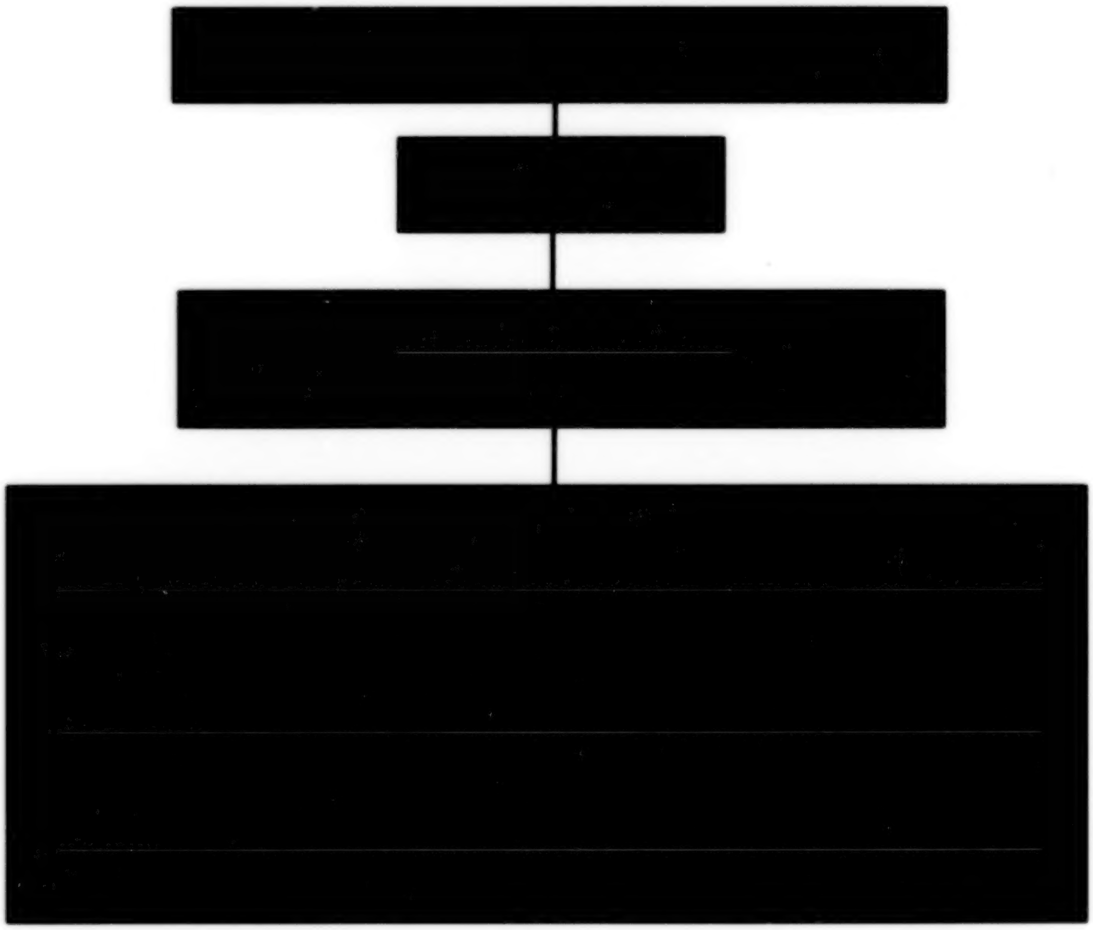
An additional 40 graduate students are selected for a science program sponsored by NASA Headquarters based on proposals by the students' advisors in a research area identified by NASA. ➤

AERONAUTICS ADVISORY COMMITTEE

NASA receives valuable guidance and technical advice regarding aeronautics research and technology programs from external sources such as the Aeronautics Advisory Committee (AAC) of the NASA Advisory Council, a primary mechanism for interacting with the external technical community of aeronautics experts. The AAC makes recommendations based upon periodic reviews of NASA's technical plans, research priorities and program progress. This advisory function provides NASA with critical guidance in planning, coordinating and assessing the aeronautics program and expeditiously transferring technology to the nation's aerospace industry.

The AAC consists of approximately 20 members from industry, academia and government selected for their expertise in specific technical areas of aeronautics. Supporting the AAC is a larger group of discipline and vehicle specialists who make up the Aerospace Research and Technology Subcommittee (ARTS). The AAC defines specific topics of interest or concern that require in-depth study or review. Technical specialists from the ARTS are selected, based on their expertise in the topical area, to conduct a detailed assessment and to develop recommendations for AAC consideration.

Given the rapidly changing nature of aeronautics, the role of the AAC is critical to maintaining an aggressive and productive aeronautics research and technology program. The continuous dialogue between OAST and the AAC assists NASA in prioritizing research efforts to meet the nation's aeronautical technology needs. ➤



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